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A TECHNICAL AND PRACTICAL STUDY OF COMPOSTING AS A SOLID WASTE MANAGEMENT ALTERNATIVE FOR THE AIR FORCE

THESIS

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The views expressed in this thesis are those of the authors and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

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THESIS

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Preface

Yard waste management is attracting increased attention as Air Force communities take a hard look at their solid waste management programs. With yard waste comprising approximately 20 percent of the municipal solid waste stream, composting can be an effective means to reduce landfill disposal and launch the Air Force toward meeting mandated reduction goals.

This thesis is designed to assist the Air Force in planning and operating yard waste composting facilities. It employs the best available scientific information to find technically simple solutions that can be implemented by Air Force personnel. Scientific principles of composting are first explained so that the "how to" recommendations may be understood.

In completing this thesis, the authors would like to thank several contributors, both outside and within AFIT. Dr. Richard Kashmanian, Regulatory Innovations Staff, Environmental Protection Agency, provided invaluable background information and personal expertise. James Hayes, also with the EPA, served on our committee and presented guidance on pollution prevention opportunities in composting. Within AFIT, our thesis advisor and committee chairperson, Lt Col James Holt, Director Environmental Masters Program, did an outstanding job of assisting us with the scope and vision of this thesis. Capt Rob Wilson was also on our committee and provided excellent comments.

More important than all of the professional comments and critiques are the opinions and support of our wives and families. While a thesis is a nice achievement, a quality home life far outways the benefits of this document. Our families have graciously accepted our long hours and time away from home.

Would we do it again? Yes, without a doubt!

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Abstract

This thesis reviews composting as a solid waste management option for the Air Force. The Air Force's Pollution Prevention Program mandates composting for every base as an opportunity to reduce landfill disposal and save future environmental costs (6:2). This research considers composting technologies used in both mixed municipal solid waste and yard waste applications. The thesis presents the technical aspects of composting and also summarizes operational techniques of successful composting sites across the United States.

Composting is a biological process for converting organic wastes into a stable product for use as a soil amendment or mulch. The Air Force should immediately begin yard waste composting programs to avoid landfill costs and to produce a natural, usable end product. This thesis is not meant to be inclusive of all information required to begin a composting program, but provides insight into the decision making process and the criteria that are important to the success of composting yard waste. Included is an outline for starting a composting program and a step by step discussion to implement low-level technology composting. The recommendations provided by this research are applicable to all Air Force bases and offer a high probability of success for attaining the Air Force's solid waste reduction goals.

A TECHNICAL AND PRACTICAL STUDY OF COMPOSTING AS A SOLID WASTE MANAGEMENT ALTERNATIVE FOR THE AIR FORCE

I. The Importance of Composting

Americans are trying to improve environmental conditions throughout the world. The cumulative impacts of our blatant disregard for the environment is producing severe adverse effects. Each of us must become actively involved to reduce the amount of pollution entering the air, water, and land.

One area where everyone can help is the disposal of municipal solid waste. The volume of waste discarded is steadily increasing as we continue our present posture of a throw away society (46:1). Reducing the volume of waste discarded in landfills reduces the demand for new landfills.

"Landfills are a necessary part of any municipal solid waste management system" (46:107). Landfills today are filling up faster than new ones can be sited and built. As old landfills close, municipalities are beginning to realize extending the life of existing landfills is an important alternative to opening new landfills. Diverting yard waste from a landfill to a composting facility reduces the waste stream by approximately 20 percent. This reduction increases existing landfill life by 25 percent, extending a life expectancy of 20 years to 25 years.

Composting moves us away from "waste disposal" toward "waste reutilization". Composting is a natural way to treat organic materials that have traditionally been landfilled. Many organic materials can easily be converted into a useful compost or mulch. It is clear that composting is sound environmental management. The composting alternative reduces waste management problems, avoids high landfill tipping fees, and produces a usable end product. Jerome Goldstein of BioCycle says:

> ... composting has become a model for the transition that needs to occur in all areas which directly affect our quality of life and how we manage present and future resources. Composting is the key to sustainable waste management, and in that context, gives us insights on how an infrastructure for sustainability can be achieved. (2:11)

Composting is a step in the right direction for Air Force communities. This thesis helps the Air Force implement composting now and leads the way beyond environmental compliance to an environmental partnership. It presents composting as an alternative to waste disposal and provides suggestions on how to make composting work for the Air Force.

II. Research Focus

Pollution Prevention

The american public is insisting on a higher level of environmental effort to clean up existing problems and to prevent future atrocities. Pollution prevention is the reaction to this demand to improve the environment. As a result, pollution prevention is sweeping industry and government alike as the key to creating an environment that is not only safe to live and work in, but also affordable and manageable for future generations. Pollution prevention is a new era in environmental management that embraces the concept of waste minimization and broadens the ethic of environmental awareness. The following definition clarifies the scope of pollution prevention.

> Pollution prevention, also referred to as waste minimization, is defined as the reduction of the quantity or toxicity of a residual waste that is generated or is subsequently processed, stored, or disposed and which reduction minimizes present and future threats to human health and the environment. (33:4)

Pollution prevention is not an environmental "program", "element", or "protocol". It is an underlying theme, a way of thinking, and needs to be integrated into every aspect of environmental management. The concept of pollution prevention impacts all media: air, land, and water.

The aspect of land management relative to pollution prevention is addressed by two main areas of waste management: 1) hazardous waste

management, and 2) solid waste management (see Figure 1).

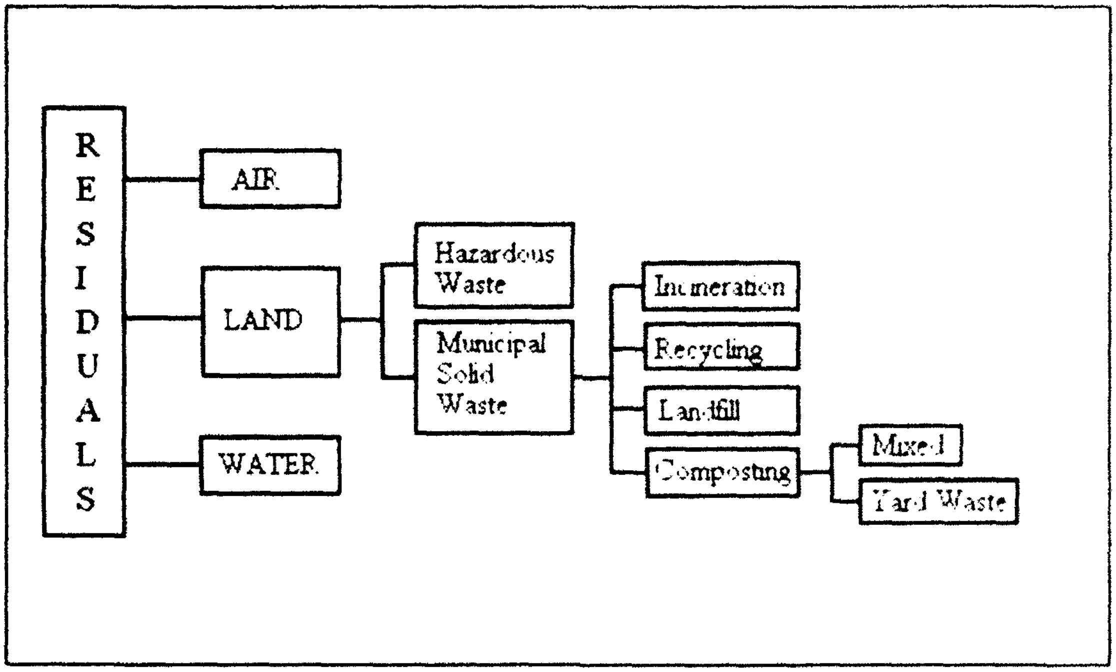


Figure 1. Simplified Diagram Showing the Pathway of Wastes

The Resource Conservation and Recovery Act (RCRA) of 1976 gives the following definition of solid waste:

> ... any garbage, refuse, sludge from a waste treatment plant, water supply treatment plant, or air pollution control facility and other discarded material, including solid, liquid, semisolid, or contained gaseous material resulting from industrial, commercial, mining, and agricultural operations, and from community activities, but does not include solid or dissolved material in domestic sewage ... (44:Sect 1004(27))

By this definition all hazardous waste is first classified as a solid waste. However, due to the specific characteristics that classify a solid waste as a

hazardous waste, hazardous wastes are regulated and controlled separately from the common municipal solid waste stream. The management of both types of waste plays a crucial role in pollution prevention. The Environmental Protection Agency (EPA) has already recognized the need to reduce hazardous waste and has developed the 33/50 Industrial Toxics Program (15). This program has voluntary reduction goals for industry and government. Hazardous waste management is an extremely large and growing area of interest. Due to this fact, the scope of this research does not include hazardous waste, but is limited to the management of municipal solid waste.

Municipal Solid Waste Management. Municipal solid waste is a rapidly growing management problem for civilian communities and Air Force bases around the country. The closure of existing disposal facilities in the United States continues to escalate the problem of overcrowded and expensive landfills (41:1). The quantity of municipal solid waste sent to landfills or otherwise disposed of needs to be reduced now by following the pollution prevention hierarchy of objectives of the EPA:

1. Source reduction: simply using less materials in production.
2. Reuse: using the same materials several times before recycling or disposal.
3. Recycling: the separation, collection, and recovery of the materials used in the production process.

4. Composting: the natural decay of grass clippings, leaves, tree and shrub prunings, and other biodegradable materials for use as a soil amendment, mulch, or landscaping material. (47:3)

Composting. Composting plays a key role in aiding the pollution prevention effort and helping to minimize the disposal of waste. "Recycling (including composting) is the preferred management option to further reduce potential risks to human health and the environment, divert waste from landfills and combustors, conserve energy, and slow the depletion of nonrenewable natural resources" (48:2). Composting not only eliminates using valuable landfill space, it turns waste into a valuable commodity.

Yard trimmings (leaves, grass, brush, limbs, etc.) alone are the second largest component of municipal solid waste, comprising approximately 17 percent of the municipal solid waste stream (see Figure 2) (45:ES-5). These items have traditionally been composted in small scale backyard operations. The commercial composting of these yard trimmings is a step in the right direction toward responsible environmental stewardship.

Regulations and Policy

On October 27, 1990, Congress passed the Pollution Prevention Act of 1990. This act establishes a Pollution Prevention Policy declaring

> ... [it is] the national policy of the United States that pollution should be prevented or reduced at the source whenever feasible; pollution that can not be prevented should be recycled in an environmentally safe manner, whenever feasible; pollution that can not be prevented or recycled should be treated in an

> environmentally safe manner whenever feasible; and disposal or other releases into the environment should be employed only as a last resort and should be conducted in an environmentally safe manner. (43:1)

This policy clearly establishes pollution prevention as an integral part of solid waste management.

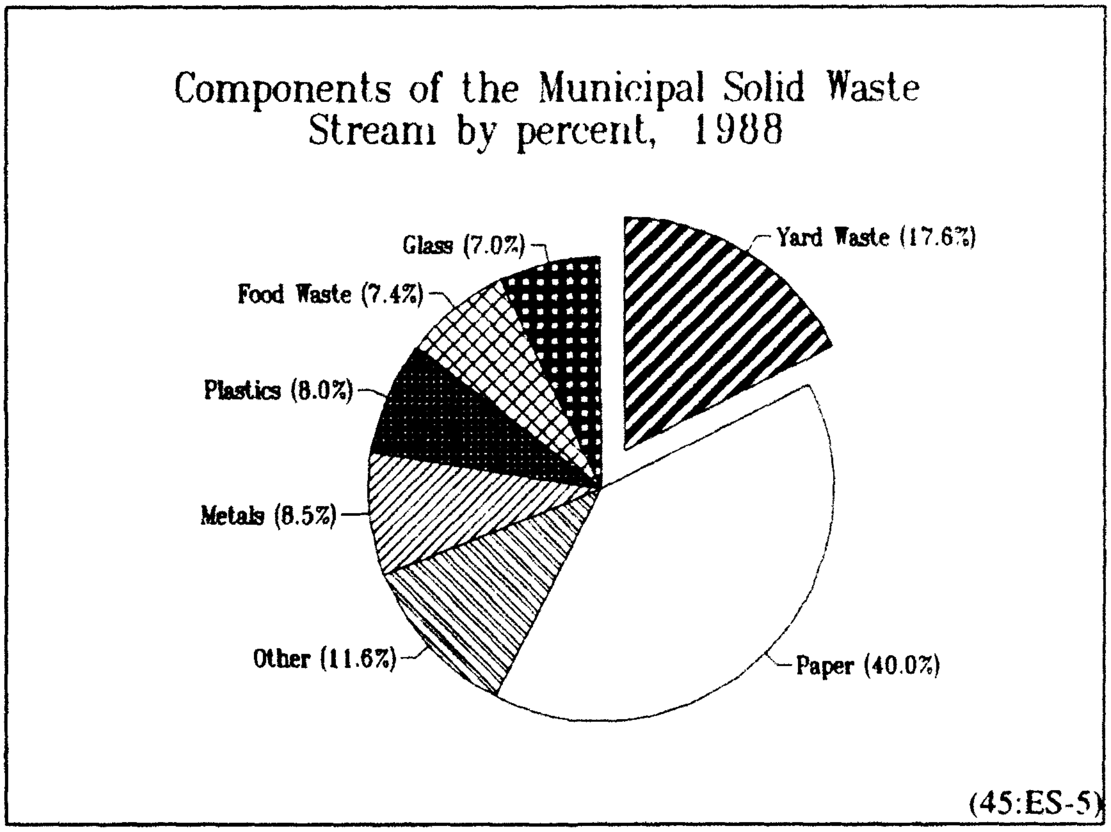


Figure 2. Components of the Municipal Solid Waste Stream, 1988

The Air Force Objective

The Air Force is interested in reducing costs by recycling and composting along with expanding and enhancing existing pollution prevention programs (6).

Base level recycling and composting programs, including education and participation of everyone on base, are important to the success of solid waste management and ultimately to pollution prevention. The rising costs of clean-up and disposal of solid waste is leading to an increased effort of pollution prevention. Pollution prevention is a direct method of cost reduction and avoidance and makes sense.

The Air Force is following the guidance of the Department of Defense (DoD) and the Secretary of the Air Force by focusing on pollution prevention as an integral part of environmental management at base level. A memorandum, co-authored by the Air Force Chief of Staff, General Merrill McPeak, and the Secretary of the Air Force, Donald Rice, sets forth the Air Force's Pollution Prevention Action Plan. One of several sub-objectives is to reduce municipal solid waste disposal 30 percent before the end of 1995 and 50 percent before the end of 1997 (36:5). The methods used to accomplish this goal include source reduction, recycling and reuse, and composting. These methods correspond to the guidance set forth by the EPA in its national pollution prevention action (47:3).

The increased concern and awareness of pollution prevention and composting has motivated government organizations to act on behalf of the people (43). Composting, as a feasible solid waste management practice, is now accepted by both the public and the federal government. In addition, because

composting is a viable option, the Air Force is mobilizing to become a leader in developing composting programs at Air Force bases. The Air Force has taken positive action by drafting Air Force Regulation (AFR) 19-4 "Policy for The Pollution Prevention Program" and by creating a new Air Staff office, the Pollution Prevention Section, within the Environmental Quality Division under the Civil Engineer (HQ USAF/CE). These actions give pollution prevention a focus and a mission from headquarters down to base level. The Air Force drafted AFR 19-4 to better define and implement Air Force strategy in accordance with existing national policies. This regulation states "every installation shall operate or participate in a recycling program and composting program conforming with regional solid waste management plans" (6:2).

Air Force leadership is dedicated to provide support toward achievement of these goals. Maj Gen Joseph A. Ahearn, the former Civil Engineer for the Air Force, stated that the "Air Force is committed to addressing environmental impacts 'up front' in our planning and base development process" (34:20). This shows that top management understands that environmental issues are important and need to be supported at every step in the design and operation of Air Force bases.

General Issue

Composting is a nationally recognized method to safely and effectively convert organic waste into useful materials such as mulch and soil amendments

(24). A variety of items found in the municipal waste stream can be composted as explained by Dr. Kashmanian, of the U.S. EPA Regulatory Innovations Branch, in the October 1990 issue of BioCycle.

> Composting can be used to convert a wide range of materials including yard trimmings, food scraps, food processing by-products, non-recyclable paper, municipal sewage sludge, and other clean, source separated, decomposable organic materials into marketable end products. (19:38)

Since most Air Force bases produce these same wastes, an active composting program at base level could help to meet the Air Force's pollution prevention goals. A comprehensive composting program would divert organic, compostable waste from landfills and process it at a composting facility for future use by the base or community. Composting will reduce waste disposal costs and reduce the need to purchase mulch and landscaping materials for the housing area and the base.

Specific Problem

Each base in the Air Force will be required to start a composting program in the near future to reduce municipal solid waste disposal (6:2). This research is an in-depth study of the composting process as a municipal solid waste management alternative. The goals of this research are to help the Base Civil Engineer (BCE):

1) understand the composting process

2) design and implement a viable composting program

3) maintain and operate the composting facility to produce a usable compost product.

Research Objectives

This research assists the BCE:

1. Determine methods of composting municipal solid waste stream components. Questions to be answered include the following:

   a. How are municipalities composting?

   b. What is being composted?

   c. What process is being used to compost the materials?

   d. How is separation accomplished?

   e. How is collection accomplished?

   f. How is the final product being used?

2. Determine basic requirements for starting a composting program. Questions to be answered include the following:

   a. What are the siting guidelines and permit requirements?

   b. What facilities and equipment are needed to operate the compost facility?

3. Determine how a consistent, usable compost product can be produced. Questions to be answered include the following:

   a. What standard operating procedures (SOP) need to be developed?

   b. What guidelines are used in the day-to-day operation of the composting facility?

c. What types of testing and monitoring procedures need to be used?

Methodology

This research examines published material and evaluates current practice to provide a valid and logical link between theory and application. The Air Force can benefit by adopting some of the proven techniques used by municipalities, communities, and private companies.

Research of Composting Guidance. The first step in developing a program for the Air Force is to analyze the theory of composting methods. This step includes an extensive literature review and personal interviews with experts in the area of composting. Chapters III through VIII cover the analysis of present literature.

Examination of Existing Composting Programs. While the theory of composting is well documented, many techniques present in theory are not used in practice. The thesis examines what processes and procedures are actually used by operating compost facilities.

Application to the Air Force. The theoretical concepts are compared to the practical applications and alternatives are analyzed and evaluated. Appropriate alternatives for the Air Force are suggested. Certain restrictions and limitations apply that are ascertained through personal interviews and background knowledge. Chapter X, Analysis of Literature and Site Visits,

addresses the feasible alternatives for Air Force guidance on developing composting programs.

Collection of Information. The data collection procedure requires the collection of information from three primary sources:

1) an extensive literature review;

2) personal interviews with experts in the area of composting; and

3) site visits of existing compost facilities.

Each of these sources provides a unique perspective to be used as building blocks to construct a valid and appropriate solution to the research objectives.

Literature Review. A thorough search of existing published material on composting provides credible information. An extensive amount of literature has been written on composting in the past several years. The literature review focuses on professional journals, EPA program guidance, and state yard waste program manuals. Computer database searches are used to explore current regulation and program changes.

Personal Interviews. Personal interviews with compost program managers determine what is presently being done. This allows a comparison between what is actually being accomplished by communities and what is written in manuals and guides. Compost managers at commercial sites in California, Oregon, Washington, Washington DC, Maryland, New Jersey, North Carolina, and Virginia were interviewed. In addition, compost managers from

municipalities in these states were interviewed to gain an understanding of the relationship between public and private composting operations.

Also, compost managers at selected Air Force bases were contacted to provide information about existing composting operations.

Site Visits. Site visits allow for personal inspection and observation of the various ways to operate a composting facility. The visits to facilities located in the states listed in the previous section provide a hands-on perspective of the methods that work and those that do not. This information, in addition to the background knowledge of the literature review and the interviews, will provide a practical understanding of the overall composting process.

III. Municipal Solid Waste Management

Introduction

Municipal solid waste disposal is one of the most serious waste management problems in the United States today. "Solid waste management is concerned with the generation, onsite [sic] storage, collection, transfer and transport, processing and recovery, and disposal of the solid waste from a technological society" (42:xiii). Economically and ecologically sound alternative methods of waste disposal must be employed to deal with ever increasing waste streams and decreasing landfill areas.

Disposal of municipal solid waste in landfills is drawing increased attention because of the value of the land, the potential health effects of improperly lined and inappropriately sited landfills, and the market value of items in the waste stream. "In many states, landfills are expanding faster than new space can be found to replace them" (25:1). Municipal solid waste management is one area that shows the greatest potential for reducing the amount of useful material that is carelessly discarded into landfills.

Municipal Solid Waste Generation and Disposal

The municipal solid waste stream is comprised mainly of wastes from residential, commercial, institutional, and industrial sources. "Solid wastes are all the wastes arising from human and animal activities that are normally solid

and that are discarded as useless or unwanted" (42:3). The average person in the United States generates more than one ton of solid wastes per year (50:i). The majority of this waste has historically been placed in landfills. Figure 3 shows the percentages of waste landfilled, incinerated, or recycled.

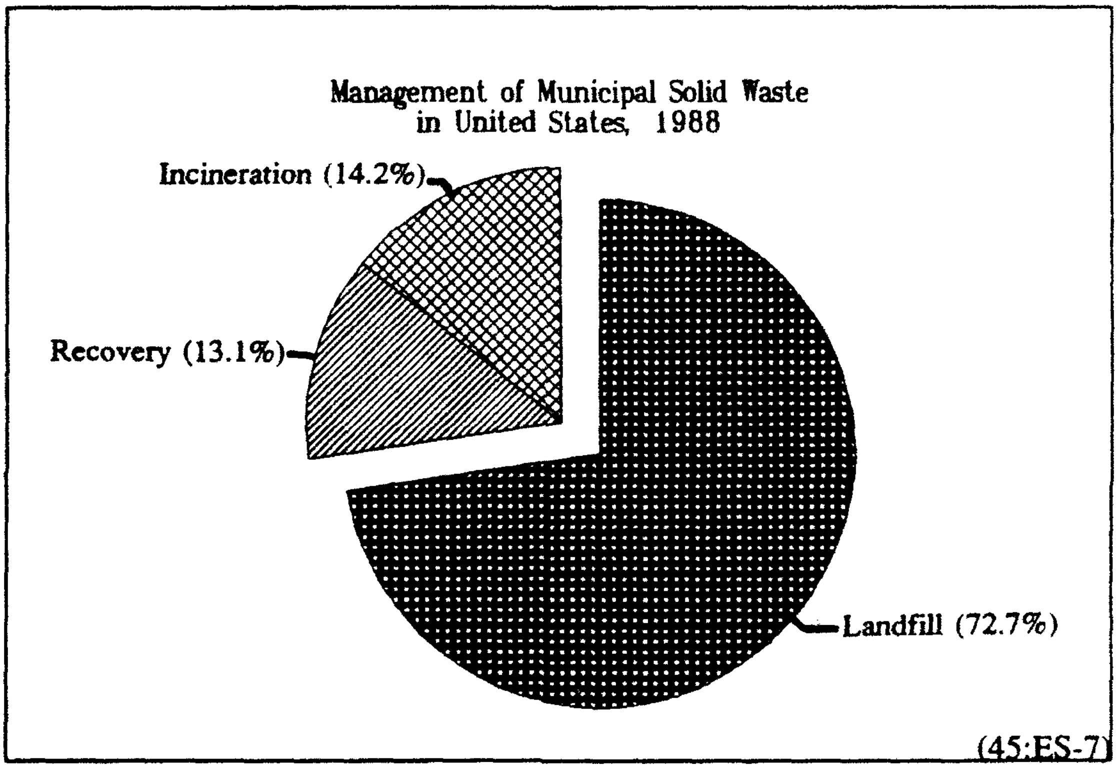


Figure 3. Management of Municipal Solid Waste in United States, 1988

The United States is now faced with a serious municipal solid waste management problem because landfill space is quickly running out. According to a study by the EPA:

> ... the United States is currently generating approximately 160 million tons of garbage per year with an expected increase of 20

percent by the year 2000. At the same time, nearly one-third of the MSW landfills in this country are expected to reach capacity between 5 and 7 years from now, while new landfills are difficult to site. (41:1)

In addition, transportation and disposal costs continue to rise and public opposition to siting new facilities continues to increase. The "not in my back yard" (NIMBY) syndrome continues to plague landfill siting with concerns over leachate and the presence of volatile organic compounds and other hazardous substances.

Source reduction and recycling have been suggested as sound approaches to solve present landfill management problems. Source reduction is the preferred choice for solid waste management. It circumvents the storage, treatment, and disposal problems by eliminating the generation of unnecessary wastes. According to the Massachusetts Division of Solid Waste Management:

> Waste volume reduction and recycling are viable waste management alternatives. The advantages of recycling include: (1) reduced volume of waste to be incinerated or landfilled; (2) decreased disposal costs; (3) reduction of adverse environmental impacts; (4) production of a beneficial material; and (5) demonstration of the viability of local recycling programs. (21:2)

Composting, as part of an integrated waste management system, can help achieve required municipal solid waste stream reductions. "A significant portion of the solid waste stream can be processed at composting facilities, including organic industrial, commercial and MSW waste, agricultural waste, sludge, and yard waste" (21:2).

Solid Waste Stream Characteristics

The solid waste stream is comprised of several different classes or types of waste. A characterization of the solid waste stream is necessary to understand the specific materials and the possible uses of each. Figure 2 (page 7) illustrates the major components of the solid waste stream. Each type of waste can be classified for a different purpose which includes recyclables, compostables, and those destined for disposal. It is important to know the usefulness of each type of waste and the proper reuse and disposal options available.

Paper. Paper waste includes newsprint, office paper, glossy magazine papers, computer paper, and corrugated cardboard (46:28). Recycling has traditionally been the method of choice for disposing of paper. Paper to be recycled is commonly divided into the following categories: old newspaper (ONP), corrugated cardboard, high-grade paper, and mixed paper (46:62).

Although paper can be recycled, it is organic and can also be composted. Recycling paper has better revenue potential so using paper as a compost product is done only when recycling is unavailable. Since most paper can be recycled in one form or another, typically only a fraction of the total amount of paper discarded is available as a compost ingredient.

Composting is dependent on the C/N ratio. The problem with

composting paper is that it is made from wood and therefore has a very high percent of carbon, yielding a high C/N ratio (3:104).

> It is important to note that fungi are the only type of organisms that can efficiently utilize woody materials and that they do not tolerate temperatures as high as some forms of bacteria or actinomycetes. Virtually no fungi survive above 60°C [140°F]. Thus the rate of decomposition of materials, like municipal solid waste with its high content of paper (made from wood), slows rapidly above 55°C [131°F]. (3:103)

Paper is a good bulking agent when a high carbon content is needed to offset a material with a high nitrogen content. This would be applicable in the case of composting sewage sludge or various manures. For the composter, paper is often substituted for sawdust as a bulking agent and is much cheaper (39:33).

Yard Trimmings. Yard trimmings include leaves, grass, brush, stumps, and wood. Composting of these materials has been ongoing in backyards for generations. When properly mixed, these materials provide a good balance necessary to produce a rich humus compost. Leaves have a high carbon content. They "are the easiest material to compost and are the most common materials handled at yard waste facilities" (46:83).

Grass has a high nitrogen content and benefits from the high carbon content of the leaves. However, grass also has a high moisture content (50-55 percent of total weight) and when mixed with leaves can cause the compost pile to become anaerobic through compaction of the pile and subsequent oxygen

depletion (11:39). Frequent turning reconstitutes the voids in the pile, replenishing the oxygen supply and helping alleviate the foul odors produced by anaerobic composting (11:71).

Wood and brush materials need to be chipped to be useful in composting. "Good results are usually obtained when the particle sizes range from 1/8 inch to 2 inch mean diameter" (3:103). Woody wastes are often used as bulking agents to help offset the effects of grass and other high nitrogen materials. Since wood is high in carbon, it will require additional time to decompose and might need to be recycled into the compost pile several times to fully decompose (37).

Metals. Metals can be divided into ferrous and non-ferrous. Ferrous metals are those metals which contain iron and are traditionally referred to as scrap metals. Examples can include cars, appliances, water heaters, pipes, and steel cans. Metals are inorganic and therefore cannot be composted. However, the most beneficial use of scrap metal is obtained by recycling. "The overall [recycling] market for ferrous metals is well established, and the demand for scrap metal is expected to remain steady or increase as processing technologies develop" (46:64).

Non-ferrous metals include aluminum, brass, and copper. Examples of products containing aluminum are soda cans, window frames, gutters, and

siding. Aluminum cans are often the financial backbone of many local recycling programs.

Glass. "Glass is also one of the most commonly recycled materials and the market for post-consumer glass has historically been steady" (46:63). Glass is often divided by color into three categories: clear, green, and brown. Since glass is also an inorganic, it cannot be composted.

Plastics. The use and diversity of plastics has risen over the last several years. Some common types of plastics include PET (polyethylene teraphthalate), HDPE (high-density polyethylene), mixed plastics (more than one type), and other plastics (PVC, LDPE, etc) (46:64). Many plastic containers are now being marked with codes (type 1, type 2, etc.) to help consumers and recyclers differentiate between the various types. Many communities are starting to recycle plastics as markets develop.

Plastics take hundreds of years to degrade and therefore are not typically compatible with a commercial composting program. Biodegradable plastic bags are receiving a great deal of attention with advocates both for and against their use at a compost facility.

Food Wastes. Food wastes consist of a wide variety of kitchen wastes, vegetable waste, and food processing scraps. These wastes

> ... can vary widely in their characteristics. Many will be too wet to have the necessary porosity and will need a bulking material. Dewatering could help reduce the amount of bulking material required. Others may need grinding to help reduce particle size.

> The C/N ratio may need adjustment; fruits and vegetables are mostly deficient in N. By judiciously blending them with other wastes, most could be effectively composted. (3:104)

The nature of food waste presents additional management concerns such as increased monitoring, rodent control, odor problems, proper segregation (such as discarding the fats), collection challenges, and mixing in a homogeneous manner (18).

Fish waste is a small part of the waste stream but an important issue to some communities near water. Minnesota has begun pilot composting programs specifically for fish waste. With bulking agents added, results show that composting is an attractive and economic alternative for disposing of fish waste (9:62).

Other Wastes. Other wastes make up 11.6 percent of the municipal solid waste stream and include rubber, leather, textiles, wood, and miscellaneous waste, each totaling less than 4 percent (45:ES-4). Most of this waste is inorganic and uneconomical to separate from the waste stream. For these reasons, it is seldom composted or recycled.

IV. The Technical Aspects of Composting

Introduction

"Composting is becoming an increasingly popular waste management option, as communities look for ways to divert portions of the local waste stream away from rapidly filling landfills" (46:81). It is an effective way of reducing the volume of solid wastes while at the same time producing a useful end product. Composting is an excellent alternative of municipal solid waste management as reported in the Yard Waste Composting Guidebook for Michigan communities.

> Composting is one of many options available for citizens and public officials alike to expand and improve the process of reducing pollution while protecting the environment. Composting program benefits include holding the line on waste disposal costs, extending landfill life, saving natural resources, and reducing the environmental hazards and pollution related to burning and landfilling. (1:iii)

Prior to the 1960's, written material concerned with refuse disposal dealt mainly with composting. Most published material was written in a popular/layman, nontechnical style. After the 1960's, authors began to emphasize the more technical aspects of waste disposal, such as incineration and landfilling, and the nontechnical writings on composting declined (13:15). However, in the past decade, published material about composting has increased substantially with the bulk of the information appearing in professional journals.

Composting

Composting is simply the decomposition of organic materials by naturally occurring organisms in the soil. According to Andreas Mayer, composting is one of the oldest recycling methods around.

> Based on the natural cycle of the earth, composting is presumably one of the oldest recycling methods developed by mankind. As early as some 2000 years ago the Roman COLUNELLA described in his textbook how to mix, stack up, and turn agricultural waste and distribute it on fields to improve the soil. So the name "compost" is derived from the Latin word "compostum" meaning "mixed, composed". (26:5)

The following definition of composting by Dr. Clarence Golueke is taken from Biological Reclamation of Solid Wastes:

> Composting is a method of solid waste management whereby the *organic component* of the solid waste stream is biologically decomposed under controlled conditions to a state in which it can be handled, stored, and/or applied to the land without adversely affecting the environment. (11:2)

Composting is the controlled biological decomposition or breakdown of organic wastes by microorganisms. These microorganisms, mainly bacteria, actinomycetes, and fungi, which are naturally present in the soil, decompose the organic material using the nutrients present as a food source (50:ii). Because composting is a biological process, only organic material of biological origin can be composted (11:6).

Composting as a waste management method is carried out under controlled conditions. This distinguishes composting as a waste treatment

process in contrast to the natural biodegradation process found in nature (11:2). The composting process is dependent on a number of important factors as explained in the Massachusetts Leaf Composting Guidance Document:

> The process is dependent upon biological and environmental factors, including the population of microorganisms, the carbon-nitrogen content of the substrate material, temperature, oxygen concentration, moisture, and pH. These factors are dependent upon one another for successful composting. (21:4)

The extent to which these factors are supplied and controlled determines the ultimate optimization of the composting process.

Microbial Systems. To fully understand composting as a biological treatment of organic waste, some fundamentals of microbial systems as they relate to the decomposition of organic and inorganic materials must be understood.

"Since composting is a biological operation, factors and requirements peculiar to the maintenance of biological activities in general affect the process" (12:15). As Dr. Golueke explains:

> ... composting is subject to well defined biological limitations which are: 1) A suitable microbial population must be present; 2) The rate and efficiency of the process are functions of the rate and efficiency of the microbial activity; 3) The capacity of a given operation is limited by the size and nature of the microbial population; 4) The substrate subject to composting generally must be organic; 5) Environmental factors are of key importance. (12:15)

The general class of microorganisms that are of interest in composting are called protists. Those protists which are most important to the composting

process are bacteria, actinomycetes, and fungi (42:282). Several studies indicate these groups of microorganisms have been found to be associated with different stages of the composting process. "Bacteria were characteristically predominant at the start of the process, with fungi appearing in 7 to 10 days, and actinomycetes becoming conspicuous only in the final stages" (12:21).

Bacteria. Bacteria are considered to be the most important microorganism associated with composting. Of all decomposers found in the compost pile, bacteria account for the greatest amount of decomposition (30:39).

Bacteria are single-celled, very small, and differ in shape and size

> Typically, bacteria are single cells - cocci, rods, or spirals. Coccal forms vary from 0.5 to 4 micrometers in diameter; rods are from 0.5 to 20 micrometers long and 0.5 to 4 micrometers wide; spirals may be greater than 10 micrometers long and about 0.5 micrometers wide. (42:282)

Bacteria are widespread with population densities differing from compost pile to compost pile. Both physical and chemical characteristics of the compost pile determine the bacterial populations present.

Most bacteria are colorless and are made up of about "80 percent water and 20 percent dry material, of which 90 percent is organic and 10 percent is inorganic" (42:282). Most bacteria are unable to make carbohydrates the way more complex green plants can, however, they can eat almost anything as explained in The Rodale Guide to Composting.

> Bacteria are the most nutritionally diverse of all organisms, which is to say, as a group, they can eat nearly anything. Most compost

> bacteria are heterotrophic, meaning that they can use living or dead organic materials, similar to fungi and animals. Some are so adaptable that they can use more than a hundred different organic compounds as their source of carbon because of their ability to produce a variety of enzymes. Usually, they can produce the appropriate enzyme to digest whatever material they find themselves on. (30:40)

Bacteria are extremely susceptible to changes in their environment and whole populations can be destroyed by sudden changes in the temperature or pH level of the compost pile.

Actinomycetes. Actinomycetes are another extremely important group of microorganisms associated with the composting process. "Species of the actinomycetes genera Micromonospora, Streptomyces, and Actinomyces can regularly be found in composting material" (11:9).

With respect to form, actinomycetes are similar to fungi. Actinomycetes grow in long filaments of nucleated cell units varying in width from between 0.5 and 1.4 micrometers (42:284).

Actinomycetes produce an earthy odor in the composting mass and are easily detected both visually and olfactorily as explained by Dr. Golueke.

> Under favorable conditions the composting material begins to acquire a faintly earthy odor after five or six days have elapsed. The odor becomes more pronounced as time progresses. ... The presence of actinomycetes does not become visually detectable (i.e., by the unaided eye) until the course of the process nears its end. When they do become apparent, they appear as a blue-gray to light green powdery to somewhat filamentous layer in the outer 4 to 6 in. (10 to 15 cm) of the pile. (11:9)

Actinomycetes are extremely active within the compost pile exerting their greatest effect on the cellulosic and woody components of the mass. Thus, they are very effective in decomposing paper which is affected very little by previous microorganisms (11:10).

Fungi. Fungi are many-celled, nonphotosynthetic, filamentous protists which are classified as heterotrophic and saprophytic. Most fungi can survive and grow in low-moisture environments and can tolerate low pH values. "The optimum pH value for most fungal species appears to be about 5.6, but the viable range is from 2 to 9" (42:284). Fungi, like actinomycetes, grow in long filaments of nucleated cell units, except their cell width varies from 4 to 20 micrometers. Fungi have the ability to decompose a wide variety of organics over a broad range of environmental conditions (42:284). Fungi perform and thrive best at temperatures around 70° to 75°F (21° to 24°C) with some forms performing at temperatures up to 120°F (49°C) (30:41).

Commonality Among Protists. In order for all microorganisms to continue to grow and function, each species must have carbon and a source of energy. Carbon dioxide and organic matter are two of the primary sources of carbon used by microorganisms for the synthesis of new cellular material. "If an organism derives cell carbon from carbon dioxide, it is called autotrophic; if organic carbon is used, it is called heterotrophic" (42:284). Energy requirements and assimilation are explained by George Tchobanoglous, et al.

> Energy is also needed in the synthesis of new cellular material. For autotrophic organisms, the energy can be supplied by the sun, as in photosynthesis, or by an inorganic oxidation-reduction reaction. If the energy is supplied by the sun, the organism is called autotrophic photosynthetic. If the energy is supplied by an inorganic oxidation-reduction reaction, it is called autotrophic chemosynthetic. For heterotrophic organisms, the energy needed for cell synthesis is supplied by the oxidation of organic matter. (42:284)

Environmental Factors Affecting Composting. The principal environmental factors affecting the compost process include oxygen concentration, moisture content, aeration, temperature, pH level, and nutrient concentration and availability. Dr. Golueke in Biological Reclamation of Solid Wastes, groups these factors under three main headings; 1) physical, 2) chemical, and 3) nutritional (11:21). Physical factors include temperature, pH level, aeration, and moisture content. The major chemical factor is oxygen concentration and the nutritional factors include the concentration and availability of carbon, hydrogen, sulfur, and trace amounts of assorted micronutrients (42:285).

Physical Factors. The most important environmental requirements affecting composting are the physical factors: temperature, pH level, aeration, and moisture content (42:285). These factors, along with technology and marketing, are capturing the major share of interest directed to composting (2:30).

Temperature. The biological decomposition of a compostable mass is temperature dependent within the ranges of the microorganisms present. The two main temperature dependent groups of microorganisms associated with composting are mesophiles and thermophiles.

Mesophilic and Thermophilic Bacteria. An aerobic composting process is sustained by the active feeding and reproduction of microorganisms found in the compost pile. Bacteria, the most important population of microorganisms, can be separated into two groups, mesophilic bacteria and thermophilic bacteria (25:9). The mesophilic and thermophilic temperature ranges are shown in Figure 4.

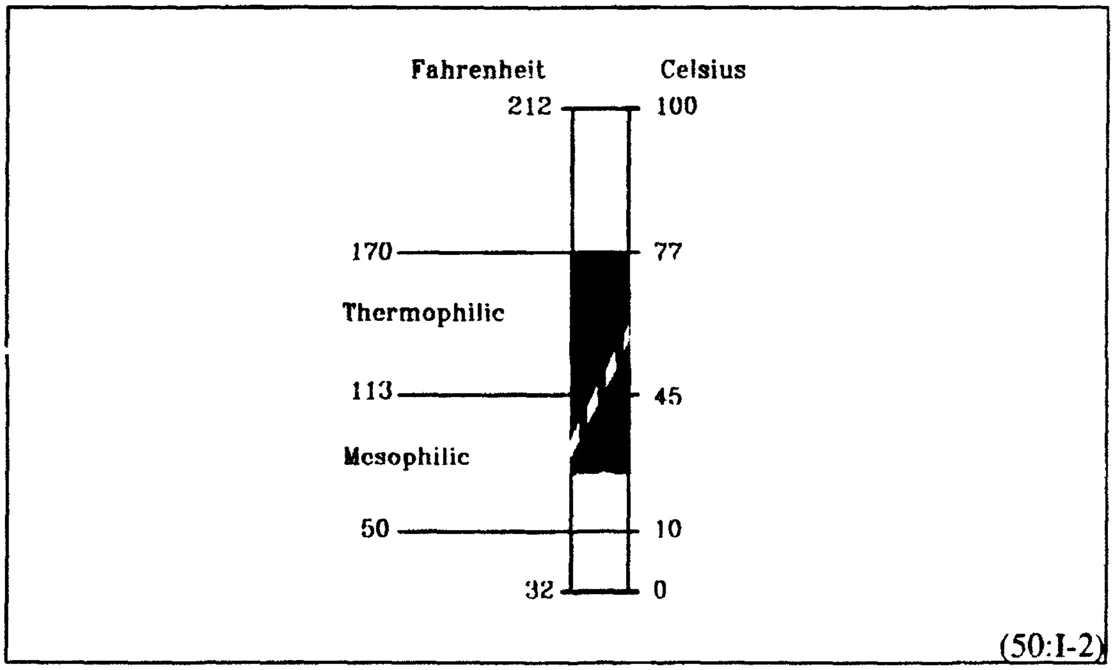


Figure 4. Representation of Mesophilic and Thermophilic Temperature Ranges

Mesophilic organisms are optimum at temperatures within the range of 8° to 50°C (45° to 122°F) (11:6). Mesophilic organisms feed on the readily available carbohydrates and proteins found in the compost pile. Heat generated during metabolism can raise the temperature of the pile to levels suitable for thermophilic organisms (25:9).

Thermophilic organisms are optimum at temperatures within the range of 50° to 77°C (122° to 170°F) (11:6). "These bacteria continue to degrade the proteins and the noncellulose carbohydrates in the compost material" (25:10). During the thermophilic phase decomposition is fastest. The active metabolic processes can heat up the compost pile very quickly (25:10).

The progression from active mesophilic bacteria to active thermophilic bacteria conditions is a natural occurrence and is inevitable unless positive measures are taken to prevent it (11:6). The thermophilic activity causes the temperature of the compost pile to rise even higher.

Because the composting process is a combination of activities of the various bacteria within these groups, the temperature at any one instant may not be optimum for each bacteria group. "It may be concluded that the optimum temperature for the process as a whole is an integration of or, perhaps better expressed, a compromise between the optimums of the various microbes involved in the process" (11:29).

The speed and efficiency of the process as dictated by microbial activity is proportional to the temperature of the composting mass.

> At temperatures lower than 30°C, a straight-line relationship exists in terms of increase in the efficiency and speed of the process and increase in temperature. The rate begins to taper off when the temperature passes 30°C and begins to approach 35°C. The slope of the curve showing efficiency of speed of the process as a function of temperature would be practically a plateau between 35°C and about 55°C - perhaps with some declination between 50° and 55°C. ... As the temperature exceeds 55°C, the efficiency and speed begin to drop abruptly and become negligible at temperatures higher than 70°C. (11:29)

Temperature rise and fall is a major characteristic of the composting process and provides an important monitoring feature of the operation. A significant rise in temperature indicates microbial activity sufficient to maintain high-rate decomposition on the compost mass. A decline in temperature indicates a decline in microbial activity. Dr. Golueke writes the following about temperature rise and fall in the compost process.

> The temperature begins to rise directly after the material is ground and stacked in a windrow or placed in a digester. Generally, there is a very short lag period - often so short as to escape detection. If no lag period occurs, it is due to the fact that decomposition has already begun at the time the material was discarded and thus became a waste. The more readily decomposable a material is, the more advanced will have been the degree of its decomposition by the time it is processed for composting. Except for brief interruptions during turning in the windrow method, the rise in temperature continues unabated until the 50° to 55°C level is attained. At this point, the rate of ascent begins to taper off until a plateau is reached at 60°C. Thereafter it hovers between 60° and 65°C and occasionally may peak at 70°C and rarely higher. (11:46)

The elevated temperatures of the compost pile are necessary for the survival of the microorganisms present. In addition, these high temperatures must be maintained at levels above 135°F (57°C) for several days to provide the necessary pasteurization required to kill pathogenic microorganisms, insect eggs and larvae, weed seeds, and other undesirable organisms (2:197; 27:15). However, to insure that all parts of the compost material are subjected to the required temperatures, several turnings or mixings are necessary.

For optimum composting efficiency and pathogenic destruction, it is suggested that the temperature levels be maintained at between 50° to 55°C (122° to 131°F) for the first few days of the process and between 55° to 60°C (131° to 140°F) until completion (42:291). Figure 5 shows changes in internal temperature of a turned windrow over time.

pH Level. The hydrogen ion concentration or pH level of an active compost pile can fluctuate between 4.5 to 9.0. Fungi tolerate a wide pH range between 5.5 and 8.0 while the active range for bacteria is between 6.0 and 7.5 (11:31).

Compost is usually acidic (low pH) during the initial stages of decomposition but quickly becomes more neutral (pH of 6 to 8) as the process proceeds. Figure 6 shows the typical change in pH of the compost over time.

The drop in pH during the early stages of the compost process is a natural consequence of the activity of acid-forming bacteria (11:31). The

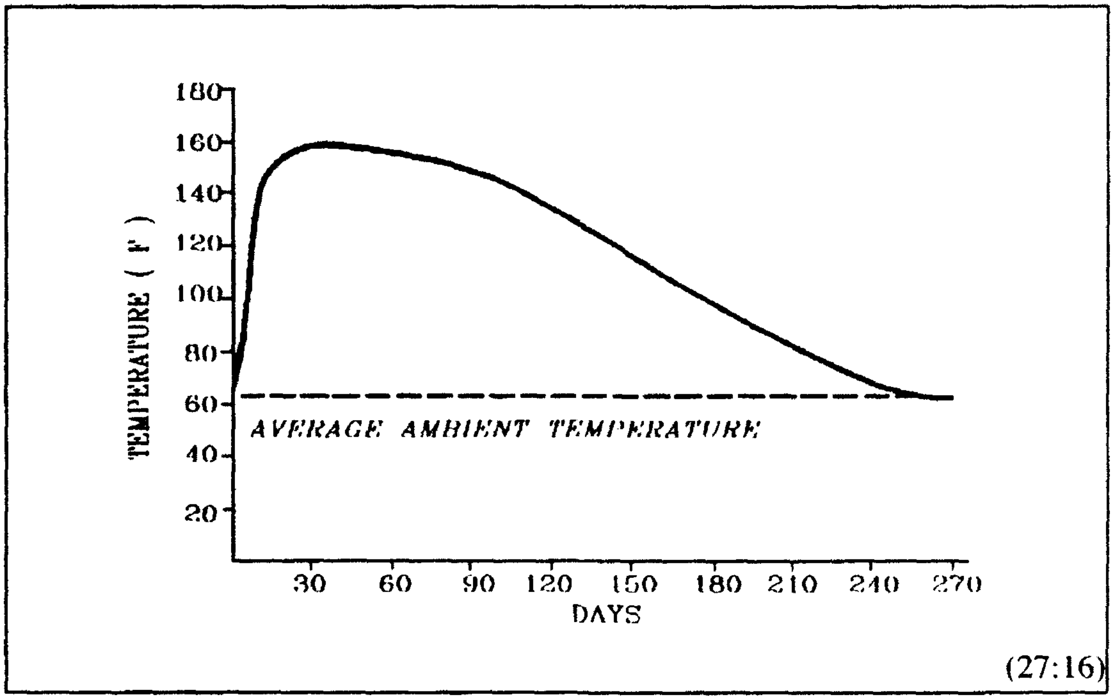


Figure 5. Changes in Internal Temperatures of a Turned Windrow

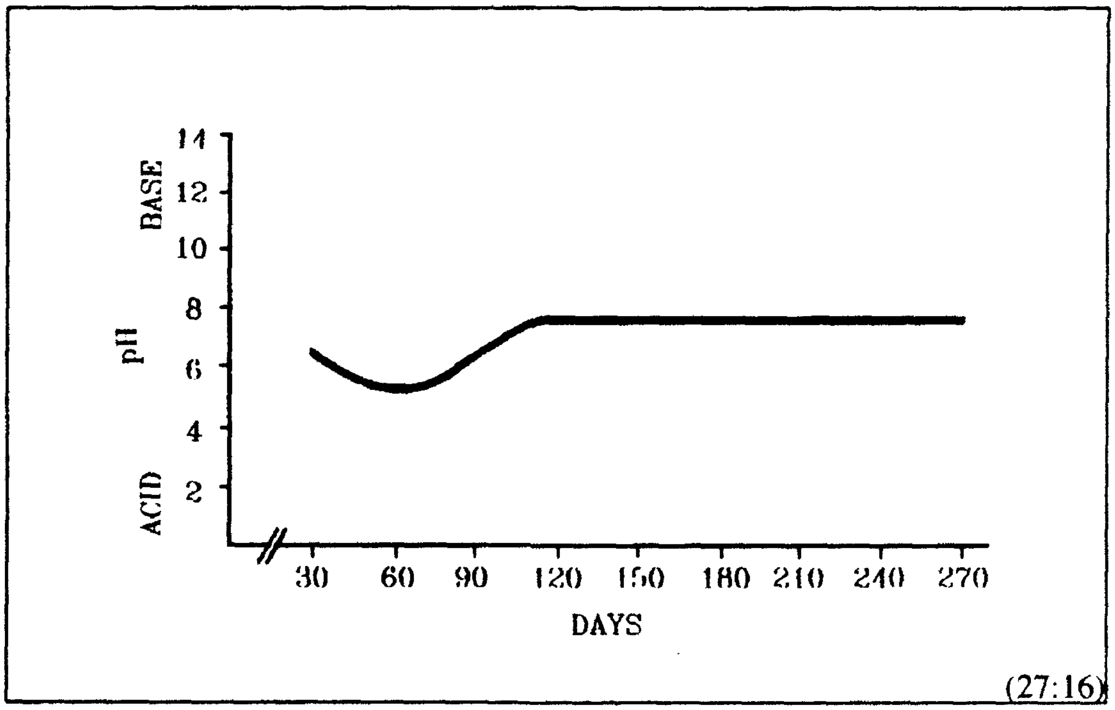


Figure 6. Changes in pH of Composting Leaves Over Time

resulting slow-down of microbial activity during this stage is only temporary and is soon rectified by the development of a new population of microorganisms capable of using the acids as a food source (11:31). Thus, adjustment of the pH is not required.

Aeration. Aeration is the process of turning and mixing the compost to provide oxygen to the microorganisms. Proper aeration is a key environmental factor. An adequate oxygen supply is necessary to maintain an aerobic composting process. Inadequate aeration can lead to objectional odors and a decrease in the decomposition rate.

Aeration is accomplished through a variety of methods. Mechanical systems can use either forced air or tumbling and stirring to attain proper oxygen levels (11:33). In windrow composting, aeration is accomplished initially through stacking and forming the windrows. As the process proceeds, the windrows must be turned and mixed to provide adequate aeration. Turning rebuilds the windrow and traps fresh air to serve as a renewed oxygen source (11:71).

The exact amount of air required for a composting mass is very difficult to ascertain and in most cases is not easily analyzed (11:33). An effective means of monitoring for an adequate oxygen supply is detection of objectionable odors. The production of putrefactive odors from an aerobic process indicates a lack of oxygen and anaerobic conditions (11:35).

Aerobic and Anaerobic Characteristics. Aerobic composting processes involve decomposition in the presence of oxygen (11:3). Air with oxygen levels greater than five percent are required for the microorganisms to sustain life (35:13). The metabolic activity of the bacteria uses the oxygen and produces carbon dioxide, water, and heat (8:47).

Dr. Golueke concludes that most modern compost systems are aerobic for three important reasons:

1. Aerobic processes are not characterized by objectionable odors.

2. Public health and crop safety come from the high temperatures that are the natural concomitants of a properly conducted aerobic compost operation.

3. Aerobic composting is more rapid that anaerobic fermentation. (11:3)

Anaerobic composting takes place in the absence of air and can be compared to anaerobic digestion as used in the treatment of sewage sludges (11:3). "The main advantages in anaerobic composting is that the process can be carried on with a minimum of attention, and as such it can be sealed from the environment" (12:14). "As anaerobic organisms decompose wastes, they produce methane, which is an odorless gas, and hydrogen sulfide, which smells like rotten eggs" (35:13). Anaerobic conditions can slow down the decomposition of the compost and produce lower pH levels (29:24). Anaerobic conditions in an aerobic composting process are undesirable and can be avoided by thorough mixing and turning of the compost materials. Because of these

problems associated with anaerobic processes, most commercial composting operations are aerobic.

Moisture Content. The moisture content of a composting pile is critical to the survival of the microorganisms present. "With composting and other biological reactions, theoretically the ideal moisture content would be one that approaches 100 percent and would be attained by slurrying the wastes ..." (11:36). In windrow composting, approximately 60 percent moisture content is ideal (35:13).

An interrelationship exists between moisture content and air supply. Both moisture and air must occupy the interstices between composting particles, as shown in Figure 7. Because of this relationship, windrow moisture content approaching levels greater than 60 percent can cause an oxygen deficiency, leading to anaerobiosis. Loss of oxygen supply due to high moisture can be corrected by proper aeration (2:30).

Excessively dry conditions will significantly decrease the decomposition rate. Generally, biological activity stops at approximately 12 percent moisture content (11:37). The rate of decomposition slows considerably as moisture content approaches this level. The moisture level of the compost mass should not be allowed to drop below 45 to 50 percent (11:37).

In windrow composting, water should be added when the windrows are formed. Initially, too wet conditions are preferable over too dry conditions.

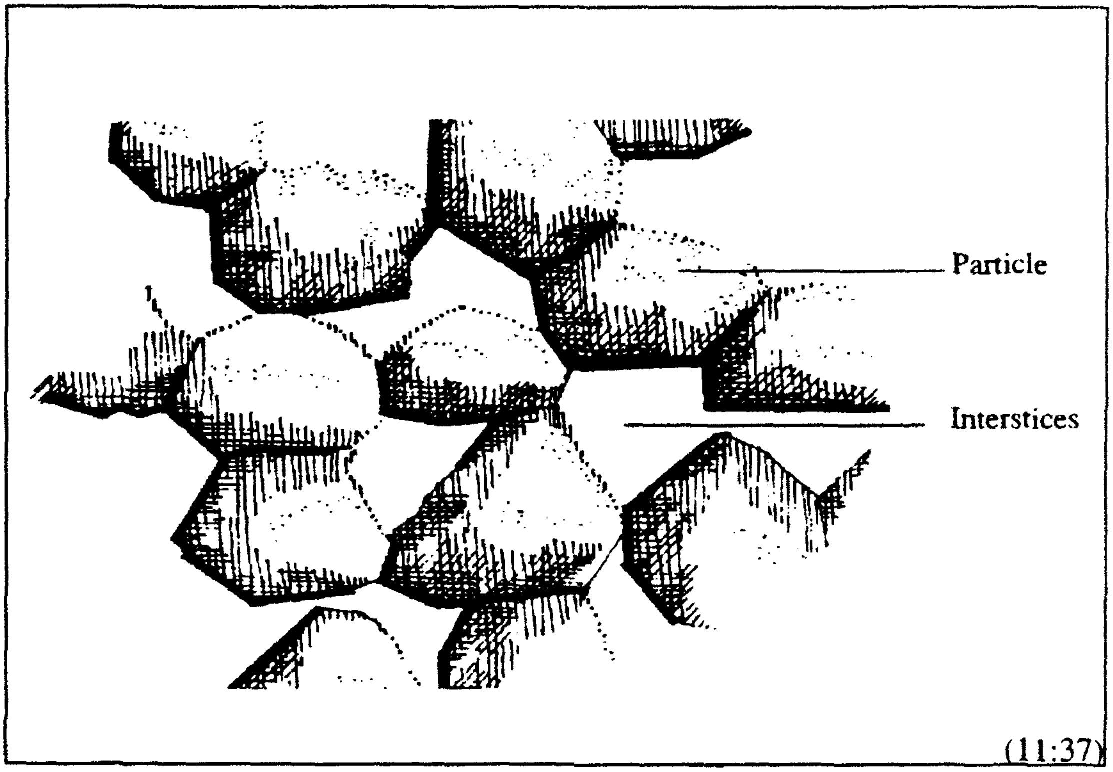


Figure 7. Interstices in Windrow Composting Material

Windrows containing high levels of water allow the composting to proceed while excess water drains from the pile or evaporates. Windrows without sufficient water will not support an acceptable decomposition rate (11:37).

The size and shape of the compost pile will influence moisture retention. A rounded or dome shaped pile will shed water. The exterior of the pile remains moist but the interior quickly drys out. A concave windrow traps water allowing it to filter down through the interior of the pile. This is illustrated in Figure 8.

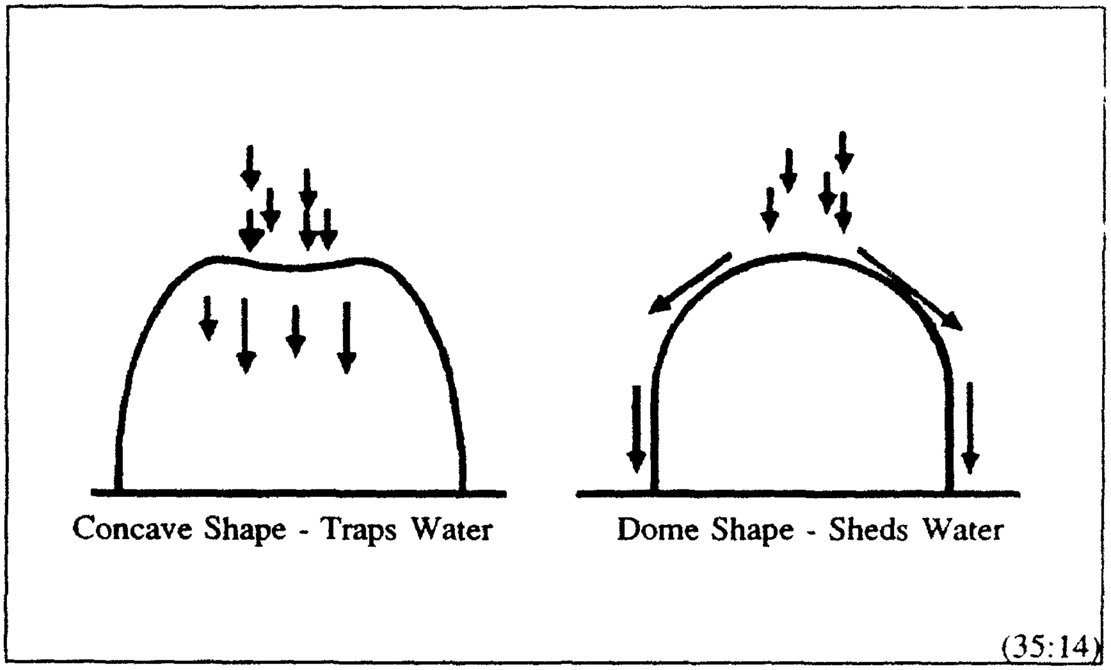


Figure 8. Windrow Shapes and the Effect on Moisture Content

Chemical Factors. Oxygen concentration is the major chemical factor affecting composting. An adequate supply of oxygen must be available to the microorganisms to sustain biological activity. Oxygen levels of at least nine percent should reach all parts of the composting material (42:291). Attainment of high windrow temperatures is possible only when an adequate supply of oxygen is available (2:197). Oxygen consumption rate is directly proportional to increases in temperature and is an excellent measure of compost activity (2:182).

Nutritional Factors. The microorganism populations found in a compost heap are dependent on the nutritional value of the compost materials.

"Essentially, it is the degree and ease of availability of nutrients to the various microorganisms, as well as the quantity and balance of the nutrients that determine the course and rate of the composting process" (11:21). To grow and reproduce, the microorganisms must have access to all the elements required to maintain their cell tissue. "This normally includes a source of carbon, hydrogen, oxygen, nitrogen, inorganic salts, phosphorus, sulfur, and trace amounts of assorted micronutrients" (42:285). Nutritional elements present in compost materials are used in differing amounts by the microorganisms. Macronutrients are those which are needed in large amounts and micronutrients are those needed in small amounts. "The principal macronutrients are carbon (C), nitrogen (N), phosphorus (P), and potassium (K)" (11:23). "Generally, elements other than the macronutrients are present in most wastes in an abundance sufficient to permit satisfactory composting ..." (11:27).

"The more abundant the elements of nutritional significance in a substrate to microbes, the greater will be the number of microorganisms supported by it, and hence the more extensively and rapidly will it be composted" (11:22).

Carbon to Nitrogen Ratio. One of the most important characteristics of a waste material that makes it suitable for composting is its carbon to nitrogen content ratio. "Microorganisms use both of these elements in a proportion that averages about 30 parts carbon to 1 part nitrogen for energy

and growth" (25:13). Nitrogen is needed for protein, body building, and population growth, and carbon is used as an energy source (17:8). This ratio of carbon to nitrogen (C/N) is a limiting factor in the composting process.

"Results of the cumulative experience of researchers in composting over the past couple of decades lead to the conclusion that a C/N ratio of about 25 or 30 parts of carbon to 1 of nitrogen (i.e., C/N 25/1 or 30/1) is optimum for most types of wastes, especially municipal refuse" (11:25). Therefore, most types of wastes can readily be degraded by the microorganisms found in a compost pile. Table 1 lists the nitrogen content and C/N ratios of various substances (11:27).

The C/N ratio usually determines the decomposition rate. Available C/N levels above 30/1 reduce biological activity, thus lengthening the time required to complete the composting process (11:24). If a nitrogen source is not added, several life cycles of organisms may be required to provide sufficient "recycled" nitrogen to reduce the C/N ratio to a suitable level. Comparatively, a deficiency of available carbon could prevent full use of all available nitrogen. Without adequate carbon, the microorganisms use all the available carbon and eliminate the excess nitrogen as ammonia (11:24).

High C/N ratios can be lowered by adding a high nitrogen source such as grass clippings or poultry manure. Low C/N ratios can be raised by adding carbonaceous wastes such as sawdust, dry leaves, or hay.

Table 1

C/N Ratio of Various Wastes

Material	Percent Nitrogen	C/N Ratio
Night soil	5.5-6.5	6-10
Urine	15-18	0.8
Blood	10-14	3.0
Leaves	---	40-80
Animal tankage	---	4.1
Cow manure	1.7	18
Poultry manure	6.3	15
Sheep manure	3.8	---
Pig manure	3.8	---
Horse manure	2.3	25
Raw sewage sludge	4-7	11
Digested sewage sludge	2-4	---
Activated sludge	5	6
Grass clippings	3-6	12-15
Nonlegume vegetable wastes	2.5-4	11-12
Mixed grasses	214	19
Paper	nil	---
Potato tops	1.5	25
Straw, wheat	0.3-0.5	128-150
Straw, oats	1.1	48
Sawdust	0.1	200-500

(11:27; 3:103; 24:110)

Public Health

The major public health concerns of composting deal with the destruction of plant and animal pathogens. These concerns are most important and must be

considered extensively when excretory wastes of humans and animals are composted.

> Composting must guarantee that all pathogenic microorganisms not indigenous in the soil and posing a danger of contamination at sufficiently high concentrations be reduced to a level that eliminates danger. (2:195)

Human, animal, and plant pathogens are found in soil, human and animal wastes, and mixed municipal solid waste. Several factors contribute to the destruction of pathogens.

> The agents and mechanisms that bring about the destruction of organisms pathogenic to man and animals in the compost process are ... heat, competition, antibiosis, destruction of nutrients, and time. (2:220)

One of the major concerns of proper temperature control during composting is ensuring sufficiently high temperatures are maintained long enough to kill any pathogenic organisms present (50:IV-2). Thermal kill points vary between pathogens. Table 2 gives thermal death points of certain fungal plant pathogens and Table 3 gives thermal death points of certain disease-causing organisms in man.

Properly managed composting provides the essential environmental conditions required for pathogen destruction.

> ... one of the major advantages of composting wastes is the destruction of disease-causing organisms. It is this characteristic that makes composting so attractive for treating certain potentially biologically hazardous wastes. ... Judging from the early literature, a characteristic of well-managed composting operations was the absence of health hazards. (11:95)

Table 2

Thermal Death Points of Certain Fungal Plant Pathogens

Organisms	Disease	Temperature (°C)
Ustilago avenae	Loose oat smut	45-53°C
U. tritici	Loose smut of wheat	45-48°C
U. zeae	Corn smut	106°C dry state 52°C wet state
Phytophthora infestans	Late blight of potatoes	45°C mycelium 25°C spores
Taphrina deformans	Peach leaf curl	46°C mycelium
Sclerospora graminicola	Downy mildew of maize	40°C conidia 50°C oospores 118°C dry state
Sclerotina fructigena	Brown rot of stone fruits	52°C
Physoderma zeae-maydis	Brown spot of corn	> 80°C
Giberella zeae	Seedling blight of corn	> 65°C ascospores
Glomeralla gossypii	Cotton anthracnose	> 95°C dry state 51°C wet, conidia
Guignardia bidwelii	Black rot of grapes	> 80°C spores
Lentinus lepideus	Brown cubical rot, Western yellow pine	105°C dry 60°C wet mycelium
Macrophomina phaseoli	Ashy stem blight of soy beans	55°C
Sclerotina sclerotiorum	Stem rot of soy beans	50°C wet, sclerotia
Pyrenophora teres	Net blotch, barley	45°C conidia 55°C mycelium
Septoria lycopersici	Leafspot, tomatoes	43°C spores

(2:221)

The extent of destruction realized during composting is a direct function of the conditions present in the process and the management before, during, and after the process. "The failure to reach 100 percent pathogen kill is a function of not providing proper conditions" (11:97).

Table 3

Thermal Death Points of Certain Disease-Causing Organisms in Man

Organisms	Temperature (°C)
Salmonella typhosa	Growth ceases at 46°C; death, 30 min. at 55-60°C
Salmonella spp	Death, 15-20 min at 60°C; 1 hr at 55°C
Escherichia coli	Death, 15-20 min at 60°C; 1 hr at 55°C
Endamoeba hisotlytica	Death, 68°C
Taenia saginata	Death, 5 min at 71°C
Trichinella spiralis	Infectivity reduces as result of 1 hr exposure at 50°C; death, 62-72°C
Necator americanus	Death, 50 min at 45°C
Brucella abortus or *sus*	Death, 3 min at 61°C
Micrococcus pyogens var. *aureus*	Death, 10 min at 50°C
Streptococcus pyogenes	Death, 10 min at 54°C
Mycobacterium tuberculosis var. *hominis*	Death, 15-20 min at 66°C
Mycobacterium diphtheriae	Death, 45 min at 55°C
Shigella spp	Death, 1 hr at 55°C

(2:222)

V. Planning a Composting Operation

Planning Factors

Planning is the core issue in developing a composting program that is focused and well managed. Appendix C provides a compost facility planning guide required for a mixed municipal waste compost facility. A summary of planning activities for yard waste compost facilities follows. Many of the ideas and considerations apply to any type of composting program and must be considered prior to starting a waste composting program.

Compostable Materials. One of the first decisions to make is what materials are going to be composted. The most common material in compost operations is leaves. Grass can be added but requires a more stringent management effort. Wood and brush are either added or chipped separately depending on end use.

Food wastes and paper wastes are also organic and are therefore compostable. The regulatory and management requirements make these items harder to justify in the composting operation. The method of composting will decide whether food and paper wastes are included.

Volume. An estimate of the amount of compostable materials to be collected is necessary. Several of the planning factors are directly dependent upon this figure. Total yard waste comprises approximately 17 percent of the

total annual municipal waste stream, but leaves alone will contribute much more during the fall months (41:1).

Another consideration is the change of seasons and how it effects the amount of leaves and grass that need to be collected. Table 4 shows an example of the variation over twelve months for leaves and grass.

Appendix F contains volume conversion and compaction data useful for estimating amounts of yard waste. The community of San Jose, California estimates their yard waste volume to be one cubic yard per household per year (38).

Collection. There are several ways to collect and transport the compostable materials from the point of generation to the composting site.

> There are three basic methods of collecting leaves for composting: a drop-off system at the local landfill or transfer station, curbside collection in bags or barrels, or bulk collection, in which leaves are scooped, raked, swept or vacuumed directly off the street. (3:19)

Table 5 lists information according to the condition of the material as it is collected. As this table indicates, the density can change dramatically depending on the method of collection.

In planning a collection system, it is important to consider the equipment that is already on hand and equipment that could be retrofitted for use in the composting operation. The existing refuse collection system must also be studied for possible changes or additional requirements. The details and options of designing a collection system will be discussed under Methods of Collection.

Table 4

Method for Estimating Monthly Volumes of Yard Waste
and Equipment Usage at a Compost Facility

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Incoming leaves (cu yd)	40%	40%					20%					
Incoming grass (cu yd)	11%	5%					15%	16%	17%	11%	10%	15%
Carry over from previous month* (cu yd)			***	***	***	***						
Total on site (cu yd)			(Monthly total = incoming volume + carry-over from previous month)									
Combining (cu yd) +												
Turning (cu yd)			(Monthly turning volume = monthly on site volume x number of turns)									
Front-end loader use (hrs) ++			(Monthly operating hours = incoming volume/rated capacity)									
Turner use (hrs) ++			(Monthly operating hours = monthly turning volume/ rated capacity)									

* For planning purposes, assume volume reduction in first month on site only; 20% volume reduction for leaves; 50% volume reduction for grass.

** Assume over-winter volume reduction of 10% per month.

\+ Assume combining involves mixing one part new material with one part windrowed material.

++ Operating hours depends on the rated capacity of the equipment and the volume of material handled per month.

(29:40)

Table 5

Density of Yard Wastes

Material	Condition	Typical Density (lbs/cu yd)
Brush and dry leaves	loose and dry	100-300
Leaves	loose and dry	100-260
Leaves	shredded and dry	250-350
Leaves	compacted and moist	400-500
Green grass	loose	300-400
Green grass	compacted	500-800
Yard waste	as collected	350-930
Yard waste	shredded	450-600
Compost	finished, screened	700-1200

(35:26)

Site Selection. The selection of a site suitable for long term composting operations also requires careful consideration. The proper site should be cost efficient and well designed. This will allow the composting facility to expand for future changes and be constructed in a location acceptable to the public.

The criteria to be evaluated in choosing a site include location, area requirements, and physical characteristics (35:39).

Location. The location of the site should minimize the distance to be traveled by collection vehicles and residents, if drop-off is applicable. Entrance to the site needs to be accessible for large vehicles and should not

increase traffic in residential areas. There should be separate access routes for heavy equipment if residential traffic is allowed.

> Sites that may be appropriate include: unused paved areas, such as parking lots; the buffer area of a landfill or wastewater treatment plant; the buffer area around industrial installations and institutions; utility right-of-ways; and municipally-owned land used for buffer areas or storage. (35:39)

Local constraints may limit the available choices since the location could also be dependent on permit requirements, zoning regulations, and land use guidelines.

<u>Area Requirements</u>. The area required for composting depends on the volume of yard waste processed and the method (i.e., level of technology) of composting. The method may be dictated by the size of an available area. The differing methods of composting will produce variable sizes and shapes of windrows, different compost time requirements, and separate processing criteria. "At a minimum, a compost site must have adequate area for at least one year's accumulation of yard waste, plus adequate additional space available to meet buffer zone requirements" (35:39).

The standard land requirement differs depending on the method of composting. Static pile composting occupies about one acre per 8,000-12,000 cubic yards of incoming material, whereas windrow and turn composting occupies one acre per 3,000-3,500 cubic yards of incoming material. Static piles are not turned as often and therefore require less open space between

compost piles. Forced aeration composting occupies one acre per 5,000-10,000 cubic yards of incoming material. The material is composted faster, thereby requiring less space, but the constant turnover of material requires extra working space.

A typical land area design for a windrow or static (leaf) pile compost facility is shown in Figure 9. Main areas include the compost pad, compost storing/curing area, staging area, and buffer area.

Compost Pad. The compost pad is the largest portion of the site and is where the windrows are formed and actual composting occurs.

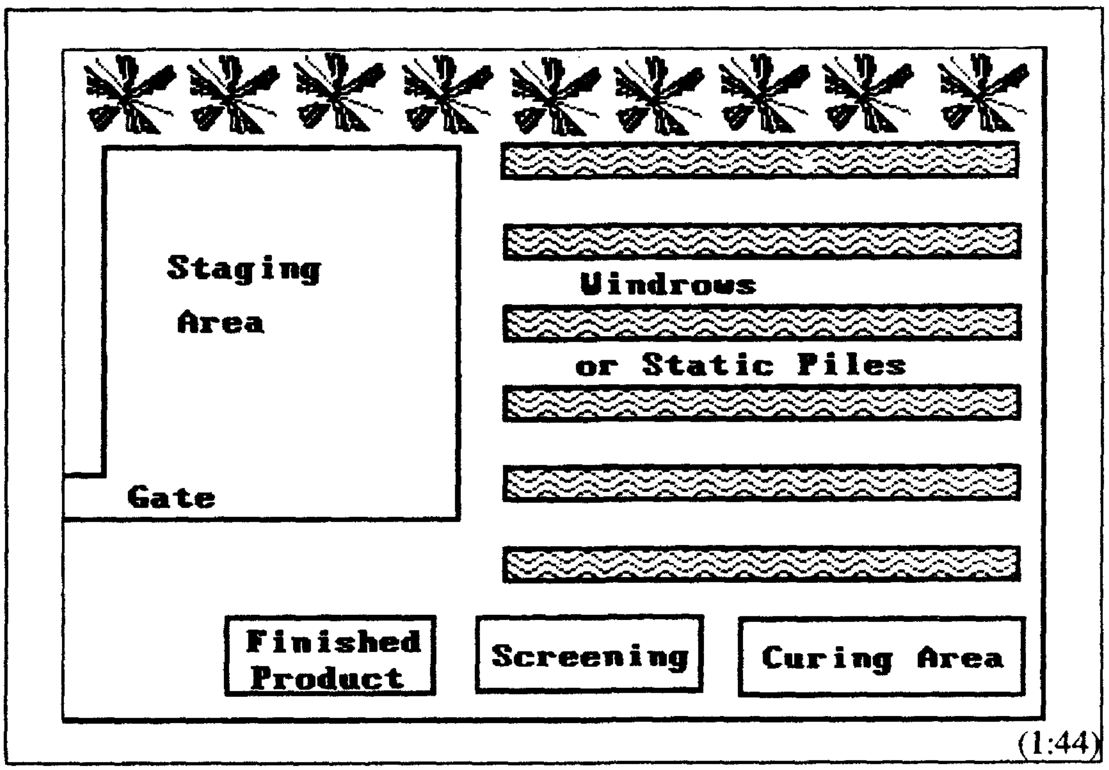


Figure 9. Generic Compost Site Layout

> The size of a windrow and the spacing between each windrow depend on the site dimensions, the equipment used to aerate the windrows, and the geographic location of the community. ... Ideal soils for the compost pad are moderate to well drained, and gently sloping for good drainage. ... Impermeable compost pads are suggested only at sites where soils are highly permeable and groundwater rises to within four feet of the surface. (35:40)

Curing Area. This area is needed to allow the compost to stabilize before being distributed to the end users. The compost will need to be stored in this area for a minimum of one month (35:40).

> During the curing stage, oxygen demand declines and the pile is recolonized by soil-dwelling microorganisms. Once cured, the compost will not generate foul odors. The curing area should be approximately one-fifth the size of the compost pad. (35:40)

Staging and Processing Area. This area receives the most traffic and needs to be well managed to alleviate any problems of congestion and confusion.

> Space is required to unload incoming yard waste, mix and blend materials, chip brush, store reject material, shred compost, and load trucks for distribution. If plastic bags are separated from the yard waste, they need to be collected and disposed of properly. (35:41)

The size of this area should be about one-fifth the size of the compost pad.

Buffer Area. The buffer zone is utilized to minimize any possible adverse effects that the composting facility may have on the surrounding area. Possible impacts include odor, noise, dust, and visual disturbances. The site plan needs to utilize existing trees and topography.

"Berms on all sides of the composting area can also help achieve noise reduction and visual screening of the site" (35:41).

Depending on the compatibility of the land use adjacent to the site, the buffer zone may need to be quite large to reduce possible adverse impacts. Many states that have enacted composting legislation have instituted specific requirements for minimum separation distances, some up to 250 feet.

Physical Characteristics. The topography and natural properties of a site are important. The main features to examine are slope and grading, groundwater and surface water separation, percolation, water supply, and security.

Slope and Grading. The slope and grading of a site is important since composting is a year round operation that is constantly subject to weather conditions. The minimum slope for a site is one percent with the optimum being between two and three percent (35:42). The proper slope will allow for adequate drainage of the site while preventing any significant erosion.

> The compost pad area needs to be graded to minimize ponding and to help maintain a stable base for equipment operation. Initial site preparation may require surfacing with gravel or compacted sand to allow year-round use. (35:42)

The local climate will dictate the necessary provisions that need to be taken to prepare for adverse weather.

Windrows should run parallel to the slope of the site so water does not flow into the piles because it would increase moisture and decrease temperature.

Preventing excess water from coming onto the site will minimize the impacts of runoff to the composting operation.

Groundwater and Surface Water Separation. Siting a compost facility within a 100 year floodplain or in wetland areas is not recommended (35:42; 40:8). The increased possibility of water on the site would make operations difficult and could hamper the composting process. Many states require facilities to be sited outside the 100-year floodplain. The purpose is to decrease the risk of leachate contamination caused by surface water runoff from the compost site.

The New York Yard Waste Management guide suggests that the "depth to seasonally high groundwater should be greater than 24 inches" (35:42). "A high water table will also increase the likelihood of leachate contamination of groundwater or nearby surface water" (35:42). The Soil Conservation Service can provide information on the depth to groundwater, percolation rate, and soil types.

Percolation. Soil percolation rates should yield a good infiltration rate to avoid standing water and potential leachate problems.

> Good soil percolation characteristics allow equipment to operate year-round. An impervious surface such as a concrete or asphalt pad offers advantages in terms of vehicle access, equipment operations, mud and dust prevention, and groundwater protection, but these advantages must be weighed against the difficulties in managing the increased runoff. (35:42)

Water Supply. Water is needed to add moisture to the windrows and for fire protection. Water can be supplied by water lines or hydrants; a nearby lake, stream, or well; or a water truck (35:43). In addition, a holding pond could be built on the site to collect runoff for reapplication to the compost piles. A moisture content of 40 to 60 percent is recommended for windrow composting (35:13). Testing may be required to ensure the runoff is free of contaminants.

Security. A gate and fence around the perimeter of the site will deter any illegal vehicular access and dumping when the site is closed. A fence can also help contain debris, such as plastic or paper bags and other lightweight contaminants, on the site.

End Use. The end use or market for the final product could determine how composting is accomplished. A thorough market survey conducted during the planning phase will ensure a product that is beneficial to the final users. If end markets are not available, the compost product may have to be landfilled. This action defeats the main purpose of composting.

As mentioned earlier, the final compost product can be used as a soil amendment or mulch. The method or level of technology of composting must be compatible with the desired end use. For example, if the end use is for flower beds and garden areas, a finer screening is required. If the end use is for

landfill cover or for roadside landscaping, a course grade is acceptable. Table 6 lists markets and characteristics of the finished product.

As shown in Table 6, the markets vary in both size and type of compost desired. The compost must be presented in a way that attracts interest in the product as a viable alternative to other processed materials. Table 7 provides guidance on how to apply the compost product for a variety of uses. This knowledge is helpful in focusing the attention of potential users on the benefits of compost.

Program Management. A compost site can be established in one of three ways: publicly owned and operated, publicly owned and privately operated, or privately owned and operated. A publicly owned and operated site is managed and fielded by public employees using publicly owned èquipment and land. A publicly owned and privately operated site has a few options available concerning the level of involvement of either party. The public entity could own the land and lease all equipment from the private company or the public entity could own the land and equipment and contract for the management and operation of the site. A privately owned and operated facility is free of all control from the public interest and is usually guaranteed minimum amounts of incoming materials to provide incentives to operate the site.

Budget. The planning and design of a compost facility is often constrained by the amount of capital available for this purpose. Appendix H

Table 6

Potential Markets and Compost Characteristics

Potential User	Use	Concerns and limitations	Comments
Homeowners	soil amendment mulch	aesthetics nonbiodegrad-ables	Practical considerations likely to preclude the use of a non Class I compost
Grounds-keepers	soil amendment mulch	aesthetics handling, non-biodegradables	
Golf courses	soil amendment nutrient source	aesthetics	A somewhat reluctant market
Nurseries (media)	high organics similar to peat	pH, soluble salts, ammonium	Potentially high paying market but stringent specs
Nurseries *(field)*	soil amendment	varies with species	Requirements less specific than for media
Parks	soil amendment	aesthetics handling	Many have own source of yard waste compost
Landscape contractors	soil amendment soil extender	handling	
Agriculture	nutrient source possible liming	nutrient content and availability handling	Large volumes of material can be distributed to one approved site
Reclamation projects	soil extender soil amendment possible liming	perhaps least demanding product specs	

(50:V-8)

Table 7

Compost Application and Use

Landscape use	Approximate Rate* (lbs/1000 sq ft)	Comments
Establish new lawns and athletic fields	3000 to 6000 (1 to 2 inches)	Incorporate into top 4 to 6 inches of soil
Topdress established lawns	400 to 800 (1/8 to 1/4 inch)	Broadcast uniformly on grass surface
Shrub and tree maintenance	200 to 500 (1/16 to 1/4 inch)	Work into soil or use as mulch
Container mix	Not more than 1/3 by volume	Blend with perlite, verm-iculite, sand, bark

* 1000 pounds = approximately 1 cubic yard

(35:63)

includes several tables and worksheets that explain in detail how to estimate start up and operating costs. The equipment required to begin an operation is the largest expense (without considering the variable price of land). Manpower requirements and the maintenance and operation of equipment dominate the operating budget. Appendix I lists types of equipment and average costs of each. Other recurring costs include testing and analysis of samples.

Process Management. Once the type of composting process (i.e., low-level windrow composting with public drop-off) is established, "proper employee training and site monitoring is critical to ensure a trouble-free composting operation" (17:2). Employees should be knowledgeable on the entire composting process and how it is effected by their specific responsibilities. A periodic training program will aid in educating the employees and will increase the effectiveness of the composting program. Efficiency will also increase as the personnel become aware of better quality management techniques and improvements to present operations.

Permits. Permits are now required in several states as legislation increases and landfill bans on yard waste begin. Contact with the local state department of environmental services will be necessary to determine the specific permits required by each state. Inquiries into local permitting requirements is also suggested.

Most states require permits for facilities over a given size (such as 3,000 cubic yards processed per year). The permit could require a plan which provides:

> ... a schematic layout of the site; a listing of equipment and personnel with their qualifications (and/or what training they will receive); an explanation of the composting process; the monitoring and record keeping techniques for both the process and the end-product; provisions for control of odors and leachate from the compost piles; and a contingency plan if the compost program temporarily ceases. (17:2)

Appendix D provides a listing of state regulations and yard waste bans and is adapted from a recent article in Landscape and Irrigation (23:16).

Education. Public education of base personnel and local citizens is critical to increase the acceptance and use of the compost facility.

> During the planning stages, public meetings should be held and/or materials distributed to explain the economic and environmental benefits of composting, as well as to alleviate concerns about its effects on the neighboring community. (17:2)

Both base and off-base residents that will participate in the program need to understand:

1) how beneficial it is to participate;
2) how they can participate;
3) how they can use the final product; and
4) how their participation helps meet Air Force goals.

Site personnel also need to be educated on the overall composting process. This will give a positive and lasting impression to various groups as they tour the site. Educated personnel can also conduct training programs on backyard composting activities and proper use of the final product.

Schedule. During the planning stage, an implementation schedule needs to be prepared. "A leaf compost facility may take up to a year or more to select, design, and build" (17:2). Figure 10 shows one example of a time schedule.

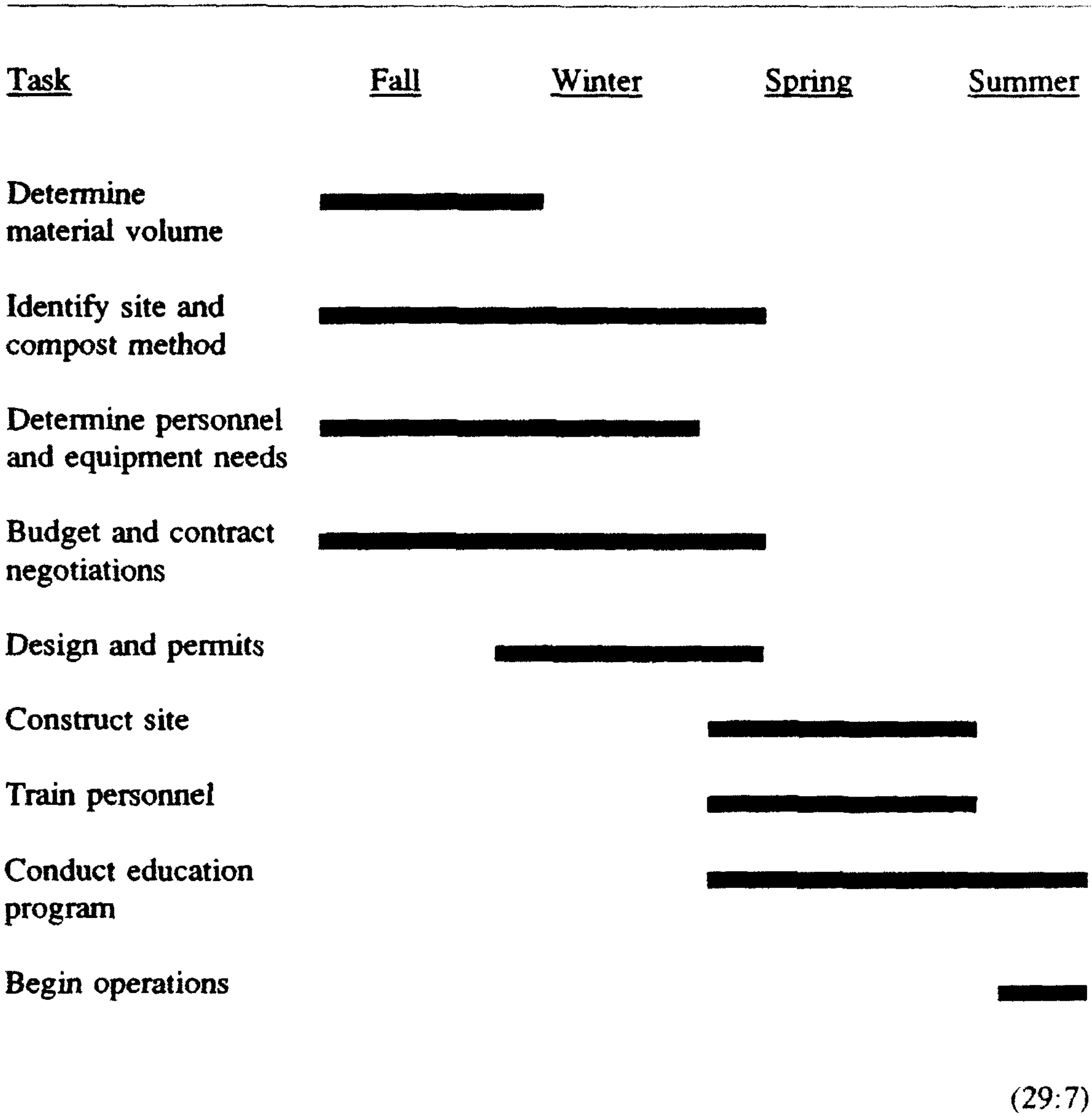


Figure 10. Projected Time Schedule for Implementing Landscape Waste Program

VI. Methods of Collection

The methods and means used to collect the incoming materials are almost as diverse as the composting process itself. The collection process will determine the ease to which the composting process can be designed. Ideally, the material should arrive on site in large trucks, free from contaminants, and not in plastic or paper bags. This is not always a feasible choice so alternatives need to be considered.

Equipment and personnel requirements need to be considered when choosing the type of collection system. Table 8 provides guidance regarding personnel requirements for various collection options.

Current collection practices and the expected volume of compostable waste are another major issue in choosing a collection method. Other issues to be considered include:

1. Effectiveness in excluding extraneous material;
2. Availability and cost of labor;
3. Existing equipment;
4. Capital, operating and maintenance costs of equipment;
5. Cost of bags (plastic, degradable plastic, paper);
6. Convenience for residents and businesses;
7. Susceptibility to adverse weather;
8. Hazards associated with placing leaves at curb or in street; and
9. Potential noise and dust from collection equipment. (17:4)

Table 4 (on page 48) provides methods for determining the equipment necessary for collection of leaves and grass for different months of the year.

Table 8

Personnel Requirements For Leaf Collection

Collection Options	Collection Equipment	Personnel Needed Per Route
Paper Bags	- Compactor truck - Open truck	- Truck operator and 1 collector - Truck operator and 1 collector
Plastic Bags	- Compactor truck - Open truck	- Truck operator and 1 collector - Truck operator and 1 collector
Loose	- Front-end loader and open truck - Street sweeper - Vacuum equipment	- Loader operator and truck operator - Sweeper operator - Truck operator and vacuum crew of 1-3 persons

(35:61)

There are several equipment options for collection of the compostable materials. Table 9 lists the major types of collection methods available for yard waste. As the table indicates, most options are available for all types of yard waste. Several of the collection methods listed below are compared in more detail in Table 10.

An Illinois study of collection programs across the country recommends two methods for organized leaf and grass collection.

1. Use of rigid, 90 gallon plastic wheeled carts with mechanical tip for the majority of grass and leaves. Homeowners could be assessed a monthly surcharge to cover the capital cost.

Table 9

Available Collection Methods of Landscape Materials

Material	Collection Methods
Grass	Claw, Rigid Cart, Bags
Leaves	Claw, Vacuum, Rigid Cart, Bags, Front-End Loader
Brush	Claw, Rigid Cart, Bags, Front-End Loader, Bundled

(29:16)

2. Homeowners could purchase supplies of degradable bags to accommodate all of their grass and leaf generation. This approach may encourage backyard composting since it would provide a direct savings to homeowners by eliminating their purchase of the bags. (29:20)

Brush should be collected separately since it is not readily composted with leaves and grass.

Table 11 provides additional insight into the advantages and disadvantages of different collection options.

Table 10

Characteristics of Yard Waste Collection Methods

	CONTAINERIZED COLLECTION		LOOSE COLLECTION		
	Packer Truck[2]	Dump Truck[2]	Vacuum Leaf[1] Collector-Truck	Mechanical[1] Claw-Truck	Front-end[5] Loader-Dump Truck
Convenience to Residential Generator	Very Good	Very Good	Good	Good	Good
Ease of Implementation[3]	Easy	Easy	Easy	Easy	Easy
Effectiveness	Very Efficient[5]	Very Efficient[5]	Very Efficient[5]	Moderately[4] Efficient	Moderately[4] Efficient
Capital Cost[6]	Moderate	Low	High	High	High
O&M Cost[7]	Low	Low	High	Moderate	Moderate
Operational Problems	Moderate	Low	High	Low	Low
Labor	Low	Low	Low-Moderate	Low-Moderate	Low-Moderate
Noise	Moderate	Low	Potentially High	Moderate	Moderate

1. Usually used for seasonal collection.
2. Used for weekly collection.
3. Includes a public education program.
4. Capture rate is approximately 90%.
5. Capture rate is approximately 100%.
6. Assumes new equipment is purchased; although use of existing equipment is very likely.
7. Cost comparison made per collection activity. Refer to footnotes 1 and 2.

Table 11

Collection Options

Procedure and\or Equipment	Advantages	Disadvantages
A. Bagged leaves	Keeps leaves out of street and prevents blowing leaves. Pickup not sensitive to weather. Pickup at low cost without specialized equipment. Instructions can be printed on bags provided by the town.	Cost of bags. Time required for debagging. Plastic in compost must be avoided.
1. Bag type:		
(a) Nonbiodegradable plastic	Lower cost of bag. Debris can be removed when bag is emptied.	Costs and possible shortage of labor for emptying bags.
(b) Biodegradable and photodegradable plastic	Little information is now available on the use of these bags foı leaf collection or how they break down during composting.	
(c) Biodegradable paper	Convenience in bagging and greater compaction than with plastic bags.	Higher cost of bag. Extra effort in the distribution of special bags. Shredding may be required. Possible increase in time needed for composting.
2. Equipment and procedure		
(a) Compactor truck	Large quantity per load due to compaction.	High equipment costs unless the compactor is used for other purposes.
(i) Empty bag into compactor	Maximum opportunity for removal of debris. Efficient dumping into windrows. Eliminates debagging operation at site.	Inefficient use of compactor.
(ii) Empty bag at composting site	Pickup may be quicker.	Inconvenience in emptying bags and forming piles or windrows.
(b) Dump truck	No specialized equipment.	Small quantity per load in absence of compaction.

Table 11 (continued)

Collection Options

Procedure and\or Equipment	Advantages	Disadvantages
B. Loose Leaves		
1. Location of piles:		
(a) Curbside	Avoid problems associated with leaves in the street.	Raking of leaves by collection crew is labor intensive, especially when collection is by front end loader. More extraneous material in leaves.
(b) In street	Most convenient collection in absence of parked cars.	Danger to children playing in leaves. Danger of fire from catalytic converters. Either raking or repeated collection if cars are parked on the street. More extraneous material in leaves.
2. Vacuum leaf collector with discharge into wire or mesh-covered box on dump truck or trailer.	Leaves are shredded to some degree and are compacted, especially if somewhat damp.	Ineffective if excessively wet or frozen. Dust if dry. Noise. Moderate expense for specialized equipment.
(a) Mounting options:		
(i) On trailer with discharge into truck	Load one truck while another is in transit.	Potential danger to operator and inconvenience from operation at rear of truck.
(ii) On front of truck (on hoist used for snow plow)	Driver can see operator.	Not generally available with belt drive.
(iii) On trailer with leaf box	Can be pulled with any type of truck including one equipped for snow plowing and sanding.	Inconvenience in backing trailer to unload. Potential danger to operator and inconvenience from operation at the rear of the truck.

Table 11 (continued)

Collection Options

Procedure and/or Equipment	Advantages	Disadvantages
(b) Drive options:		
(i) Belt	Belt drive reduces vibration from impeller to engine which reduces maintenance costs and increases service life.	Higher initial cost
(ii) On engine crankshaft	Lower initial costs.	Vibration from impeller increases maintenance costs and decreases service life
(iii) Power take-off	Intermediate cost relative to other options	Intermediate cost relative to other options
3. Catch basin cleaner	Large units (12 inch suction hose) are fast and effective with sufficient suction for collection of wet leaves.	Small units (6-8 inch suction hose) are slow and clog in excessively wet or freezing conditions. Very high initial costs. Rather high maintenance costs. Noise.
4. Front end loader and dump truck	Specialized equipment is optional. Effective with wet and/or slightly frozen leaves. Efficiency can be increased if front end loader works with a small snow plow and final cleanup is with a street sweeper.	Leaves must be raked into the street. (A tractor-pulled rake can be used only in suburban areas.) Inefficient with dry leaves.
5. Front end loader and compactor truck with chute for receiving leaves.	Same as in number 4 except that effective capacity is much greater with a compactor.	Same as number 4.

(17:6)

VII. Composting Processes

Introduction

The composting operation is the process by which the incoming product decomposes into the finished compost product. It does not include the planning, collection, or distribution. There are several different methods used to effectively produce a compost product that can be used as a soil amendment, mulch, or land cover. Composting operations can vary with land area constraints, collection methods, types of incoming materials, equipment required, monitoring and testing needed, costs, and end use.

Two main categories of composting the municipal solid waste stream are mixed municipal solid waste composting and yard waste composting.

Mixed Municipal Solid Waste Composting

> Municipal Solid Waste (MSW) composting is a developing waste management technology in the United States. Unlike yard waste composting, a large amount of pre-processing of incoming materials is required prior to composting. Pre-processing is performed to isolate the compostable portion of the municipal solid waste stream (yard wastes, food wastes, and organic fractions such as paper). These materials can constitute anywhere from 30 to 60 percent of the municipal waste stream (Chertow, 1989). (46:88)

Municipal solid waste composting is one part of an overall integrated waste management strategy. A large capital investment is required to build the necessary facilities. A municipal solid waste composting system must not only

be concerned with compostable materials, but also with the items that are separated before the composting process such as metals, glass, plastics, appliances, and other bulky items. "The compostable fraction of MSW is usually composted in a manner similar to the high-level technology approach for yard wastes. Forced aeration and frequent turning are used to foster optimum composting conditions" (46:89).

Since the entire waste stream enters the waste management facility, this type of composting encompasses the largest variations in the items used for the composting process. The complete organic waste stream is typically processed through the composting system due to the difficulty of separation into yard waste, food waste, and paper waste.

Municipal Solid Waste In-Vessel Composting. In-vessel systems are frequently used to compost municipal solid waste. The facility is enclosed and the incoming product is the entire municipal solid waste stream. The composting is contained within the system and is not exposed to outdoors until the final curing process.

> Sometimes called 'digesters', in-vessel systems use forced aeration and turning in large, enclosed chambers to produce the compost product. These systems claim to provide a more consistent product and have fewer odor problems than the windrow or static pile variety. In-vessel composting is sometimes followed by a windrow step to further compost the materials. (46:89)

Several large communities are contracting for large municipal solid waste composting facilities to be built and managed. One example that has received a

great deal of attention is the facility built and operated by Riedel Oregon Compost Company, Inc. (ROCCI) located in Portland, Oregon. The ROCCI solid waste composting plant cost $28 million to build and has a capacity to process 600 tons per day. It began operating in April 1991 but had "to cease accepting garbage as of January 31, 1992 ... [ROCCI] stated that the plant has experienced a number of operational difficulties, including odor emissions" (32:6). This is a costly case where the in-vessel system was not able to contain the odors.

The large capital investments necessary to begin an in-vessel operation are risky. "The major risks typically addressed in recycling/MSW composting transactions include construction, waste supply/revenue, technology, environmental, and change in law" (5:55). An advantage to municipal solid waste composting is that the final product is produced in known, reliable quantities which attracts large scale buyers (46:89).

The design and operation of in-vessel systems are typically highly engineered to produce a compost product much quicker than windrow composting and even some forced aeration systems. "In vessel systems digest material for two days to four weeks, and curing usually takes another four weeks (Chertow, 1989)" (46:89).

Yard Waste Composting

Yard waste comprises approximately 17 percent of the municipal waste stream. It can be easily separated from other components of the waste stream and is completely biodegradable (45:ES-5).

> Yard waste generation rates and composition vary by season, year and region. In fact, during the peak months of their generation (i.e., primarily during the summer and fall months), yard wastes can represent 25-50 percent of the MSW stream. (41:1)

Given the already separated materials, yard waste composting is a natural alternative to landfill disposal. A large number of local communities, counties, and companies have begun yard waste composting. Table 12 shows the number of composting facilities in operation in the United States.

Table 12

Active Yard Waste Composting Facilities in the United States

Year	Number of active composting sites
1988	651
1989	986
1990	1500
1991	2200

(18)

Windrow Compost Operations. The actual yard waste composting process is comprised of several steps, each of which are important to the successful decomposition of the organic materials. Figure 11 provides a clear outline of the actions required to produce a usable end product using windrow composting.

The process begins with the planning, design, and preparation of the compost site. The material is then collected and delivered to the staging area. At this time the material can be debagged if desired and the brush and wood can be separated from the leaves and grass. A shredder or grinder is then used to decrease the size of the material and create a homogeneous mixture. The required water is added to ensure a proper composting environment.

The windrows are formed using front-end loaders. Depending on the type of turning equipment, the windrow sizing and layout will vary. Figure 12 gives one example of the differences in windrow formation.

The size of the windrow is an important aspect of the composting process. The length of the windrow is not crucial and can be any convenient length. However, the height of the windrow is crucial and must be controlled. "If piled too high, the material will be compressed by its own weight, pore space will be lost and the mass becomes anaerobic" (12:52). In addition, the height of the pile is directly proportional to its internal temperature. A compost pile that is too high will get excessively hot - above 70°C (158°F), while a pile

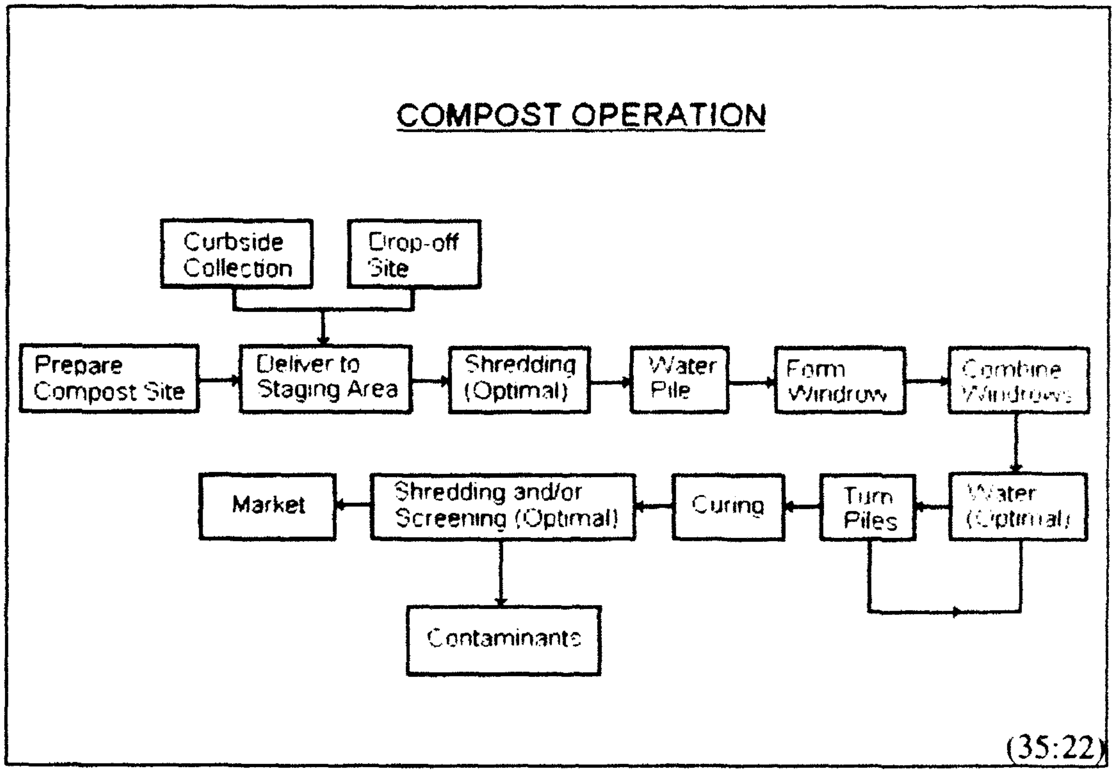


Figure 11. Windrow Composting Operations

that is not high enough will not maintain temperatures optimum for thermophilic organisms (12:52).

Once the windrows are formed, initial decomposition and settling will cause a decrease in the volume of the windrows. This will necessitate combining windrows to maintain optimal windrow shape and composting conditions. "The principle of the mixing technique is to move the top of the windrow to the bottom of the windrow being formed, mixing the leaves well during this process" (see Figure 13) (17:18). Additional watering may be

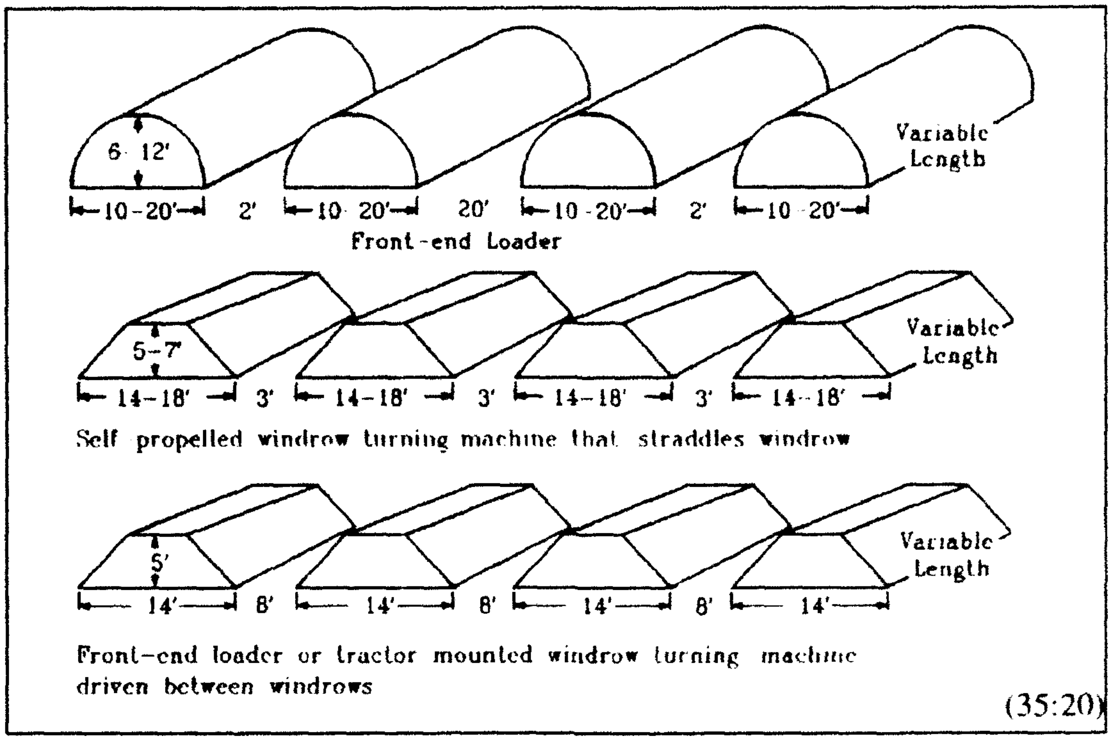


Figure 12. Turned Windrow Site Profile

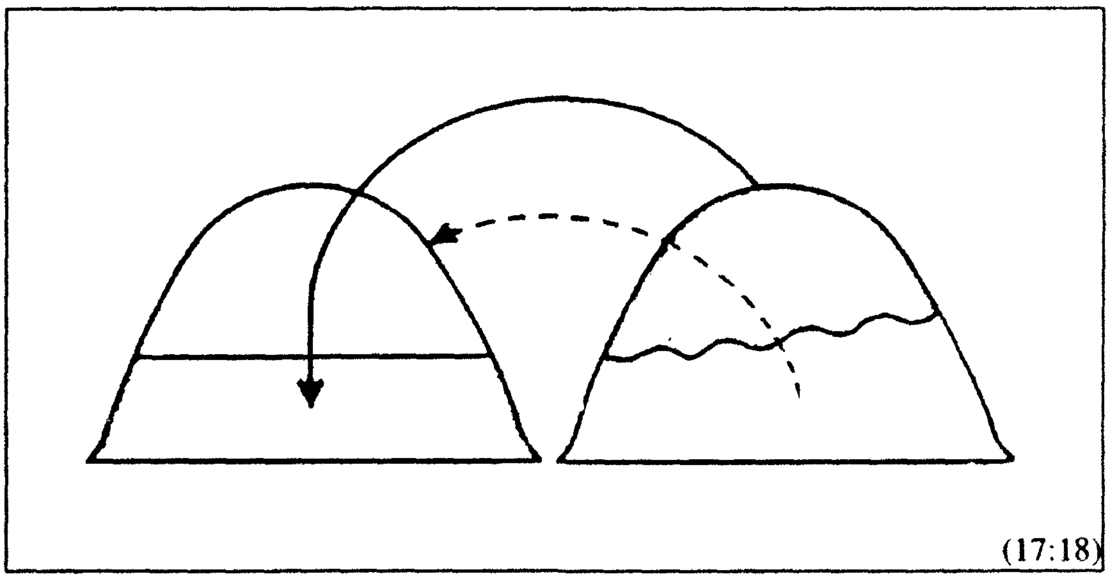


Figure 13. Windrow Turning for Aeration and Mixing of Compost

necessary for dryer climates and leafy wastes. Turning the piles will continue to ensure optimal conditions and will increase the rate of decomposition.

The compost is ready for curing when the rate of decomposition diminishes and the piles are near ambient temperature. Curing provides an extended period for the compost to fully stabilize. Stabilization is the stage in composting following active decomposition; characterized by slow metabolic processes, lower heat production and the formation of humus. Final shredding and/or screening will enhance the quality of the final product by reducing the amount of contaminants and eliminating any materials that have not fully decomposed. The compost product is now ready to be marketed for a variety of end uses.

The windrow composting process can be as short as a few months or as long as several years. A complete discussion of the different composting systems is included in System Variations which follows. Prior to a detailed discussion on the ways to compost, it is important to understand the types of waste expected.

Waste Types. Yard waste consists of leaves, grass, and woody products such as brush and limbs. The materials used and the ways in which they are mixed vary widely between compost facilities. Several surveys have been completed which reveal the types of yard wastes composted.

Dr. Richard Kashmanian completed a study of eight composting programs in 1988. Of the nine total sites reporting:

- Four of the nine (44%) only composted leaves
- One of the nine (11%) only composted grass
- Three of the nine (33%) composted leaves and grass
- One of the nine (11%) composted leaves, grass, and brush (41:32)

BioCycle also completed a survey of eleven composting facilities in the summer of 1990. The results showed that:

- None of the eleven sites only composted leaves
- None of the eleven only composted grass
- Three of the eleven (23%) composted leaves and grass
- Eight of the eleven (73%) composted leaves, grass, and brush (10:31)

These findings do not agree on the specific percentages, but the results do point to one major similarity; grass is combined with leaves and/or brush in the majority of these cases.

Leaves. Leaves are the natural basic ingredient in yard waste composting. A detailed mineral and physical characterization of several popular leaf types is shown in Table 13.

> Pound for pound, the leaves of most trees contain twice the mineral content of manure. The considerable fiber content of leaves aids in improving the aeration and crumb structure of most soils. (24:95)

Only one of the twenty sites listed above does not compost leaves. There are relatively no disadvantages to composting leaves and they pose little management problems compared to other materials.

Table 13

Composition of Fallen Leaves

Name	Calcium	Magnesium	Potassium	Phosphorus	Nitrogen	Ash	pH
Ash, white	2.37	0.27	0.54	0.15	0.63	10.26	6.80
Beech, American	0.99	0.22	0.65	0.10	0.67	7.37	5.08
Fir, balsam	1.12	0.16	0.12	0.09	1.25	3.08	5.50
Hemlock, eastern	0.68	0.14	0.27	0.07	1.05	-----	5.50
Maple, red	1.29	0.40	0.40	0.09	0.52	10.97	4.70
Maple, sugar	1.81	0.24	0.75	0.11	0.67	11.85	4.30
Oak, white	1.36	0.24	0.52	0.13	0.65	5.71	4.40

(24:97)

Leaves can vary with the type of trees but the management of the process does not change. New Jersey's Leaf Composting Manual has the following example of leaf types.

> Maple leaves decompose more rapidly that oak leaves, and other leaf types doubtless differ in this respect. Mixtures would ordinarily be received at a leaf composting facility, and no specific recommendation is made based solely on leaf type. (40:4)

Oak leaves are oily by nature and will slow the composting process if shredding and proper mixing with other leaf types is not accomplished (31). Pine needles are compostable but break down slowly. Also, pine needles are acidic and

should not be used in large quantities unless composting for acid loving plants (24:101).

Grass. Grass composted with leaves is an issue with advocates on both sides. From these surveys, grass is composted together with leaves, however, composting grass is more difficult. An article in The BioCycle Guide to Yard Waste Composting states that "after a community has one or more years experience with leaf composting, it may wish to incorporate grass clippings into its composting operation" (3:75). The main reason is that grass clippings require more frequent turning and must be managed as soon as they are on site to avoid odor problems (3:75).

Grass should be mixed with leaves at "a ratio of 3 volumes of partially decomposed leaves to 1 volume of grass clippings" (40:22). It is a trial and error process that will take a few seasons to perfect on any given site.

> The partially composted leaves act as a bulking agent to improve penetration of oxygen to the grass clippings. The grass in turn speeds the decomposition of the leaves by providing needed nitrogen. The end result is a higher quality compost product which is ready in a shorter period of time. (40:22)

Composting grass brings up the issue of fertilizers and weed killers used on lawns. The compost end use should not be affected by the normal use of these materials. "Grass may have concentrations of herbicides (weed killers) used in normal lawn maintenance programs. Once applied to turf the herbicide

may take a few weeks or months to degrade to a relatively harmless state" (17:18).

Wood and brush. Wood products are either incorporated into the composting mix or are chipped separately. If the wood products are ground and mixed in, a screen will be required at the end of the process to eliminate any large undecomposed pieces from remaining in the compost (37; 14; 28). These larger pieces are either reincorporated into the beginning of the process or are used separately as wood chips.

Another choice for wood products is to grind separately for several end uses. The Leaf Composting Manual from New Jersey recommends the following guidance on woody materials.

> Wood tends to decompose very slowly, making composting of woody materials impractical in most cases. Thus woody materials should not be intentionally incorporated in leaf composting windrows. Small amounts of incidentally included branches and twigs pose little problem. (40:23)

Some communities use the wood chips as fuel for heating (38; 14; 28). Others keep the chips separate and mix the finished compost in after it has been cured to produce a mulch product (16). Firewood is also an option for the large pieces of wood and brush. Figure 14 summarizes the preceding discussion of wood products and how they are used in the composting process.

1. Chip the wood as it enters the site and use it immediately as a fuel or mulch.

2. Chip the wood as it enters the site and incorporate it into the compost pile. Screen out the large pieces at the end of the process and reincorporate them.

3. Chip the wood as it enters the site but keep it separate. Mix the finished compost with the wood chips to produce a mulch.

Figure 14. Three Uses of Wood Products in Composting

Composting Source Decisions. There are a myriad of options available for choosing the types of materials to include in a yard waste composting program. Table 14 lists advantages and disadvantages to several of the material options.

System Variations. Yard waste is composted in a variety of ways. Composting systems can be defined by two different categories that overlap but are distinct. The first category defines composting by processing methods. The second category defines composting by levels of technology.

Yard Waste Composting Methods. The four yard waste composting methods are passive leaf piles, windrow and turn, aerated static pile, and in-vessel composting. Each of the four methods has distinct advantages and uses. The methods mainly vary on equipment and operations cost, land area required, time to compost, and end product use. The most common method for

Table 14

Evaluation of Yard Waste Materials

	Advantages	Disadvantages
Leaves	Few odor problems Composts aerobically No pesticide issues Can be composted separately Requires little or no turning if desired	High carbon content which slows down decomposition Requires additional watering Rough on blades of turning machines
Grass	Decreases decomposition time High in nitrogen Balances C/N ratio High moisture content (50-60%)	Can easily become anaerobic and cause odor problems Needs to be mixed thoroughly with leaves Must be turned more frequently
Wood & Brush	Can be separated for chipping/shredding Bulky for mulch and landfill coverings	Does not decompose well with leaves and grass due to high carbon content

leaf composting is windrow and turn (17:9). The following excerpt is from Connecticut's Leaf Composting - A Guide for Municipalities and describes these four methods of composting with the information summarized in Table 15.

> Passive Leaf Piles: Leaves are deposited in piles ranging in height from 9 to 20 feet and are left undisturbed for a minimum of two to three years. Leaf piles that are too small (less than 6 feet high) should be combined. An optional measure is to turn and aerate the leaf pile in the early spring or late fall. Although process management is minimal, the leaf piles should be maintained to avoid and unsightly appearance and should be combined after there is a noticeable volume reduction from the initial leaf pile size. Odor may be a problem when these piles are disturbed as anaerobic conditions may exist in the oxygen starved center of the pile, so wind directions should be considered before work on the piles is undertaken. Compost consistency for end use is fair, as it may retain clumps of uncomposted leaves.
>
> Windrow and Turn: Leaves are deposited on a compacted pad to form a triangular shaped windrow measuring 10 to 20 feet at the base with a height of 6 to 12 feet or higher. The windrow length can be up to several hundred feet long or as long as the site allows. In this process, the windrows are turned periodically with a front end bucket loader or a special turning machine and water is added as needed. The frequency of windrow turning is determined by the temperature and moisture content of the windrow. Windrows are combined as they shrink in size. The leaves compost through the winter and spring, cure over the summer and are available for end use by the next collection season. The finished compost can be removed from the composting site to make room for incoming leaves. The consistency of compost for end use is good as periodic turning will result in fewer clumps of undecomposed leaves.
>
> Use of specialized windrow-turning machines improves aeration, resulting in shorter time requirements for composting. The turning machine is either self-propelled or machine driven. If machine driven, it is important that the drive method selected be properly matched to the machine.

With windrow-machine turning, the machine selected limits the windrow height to 5 to 7 feet. Windrow width varies from 14 to 18 feet to give a trapezoidal shaped pile.

Aerated Static Pile: The windrow configuration is similar to that described for windrow and turn except that the windrow is stationary (static pile) and has a base of wood chips or some other porous material. Since the leaves are not turned in this process, it is particularly important that non-compostable materials are removed before windrow formation. The leaves are also put through a tub grinder or shredder before forming the windrow. A perforated plastic pipe is placed over or in the base material and air is forced through the pile into leaves using an air blower. After the windrow is formed, a 4"-6" layer of compost, wood chips, sawdust, or an equivalent porous material is placed over the pile to help retain process heat, moisture and odor. In order to manage windrow temperature the air movement is controlled either by a timer switch or manually. Experience with this method for composting leaves is limited. It is generally used in sewage sludge composting.

In-vessel Composting: *In-vessel composting* encompasses a variety of systems involving mechanical agitation, forced aeration and enclosure within a building. These systems are designed and supplied by consultants or commercial suppliers. They are generally not economically feasible for composting leaves alone, but may be appropriate if sludge disposal is an issue. The advantages include fast processing, avoidance of weather problems and better process and odor control. (17:8)

Yard Waste Composting Technologies. Another method of describing the various approaches to yard waste composting divides the process into four levels of technology: minimal-level, low-level, intermediate-level, and high-level. The actual processes are very similar to the four methods described above but understanding the terminology is necessary.

Table 15

Leaf Compost Guidance Summary

Parameter	Method		
	Leaf Pile	Windrow and Turn	Forced Aeration
1. Site information.			
Site: cubic yards leaves/acre	8,000-10,000	3,500-8,000	5,000-10,000
Surface	Earth pad	Earth pad (paved surface acceptable)	Earth or paved
Grade	2% slope (min)	2% slope (min)	2% slope (min)
Drainage			
Subsurface	Moderate	Moderate	Moderate
Surface	Satisfy acceptable water quality criteria for discharge (or contain on site if needed). Divert surface water from piles.	Satisfy acceptable water quality criteria for discharge (or contain on site if needed). Divert surface water from windrows.	Satisfy acceptable water quality criteria for discharge (or contain on site if needed). Divert surface water from aerated windrows.
2. Suggested separation distances (in feet) from compost site.			
To residential and business complexes	200-250'	200-250'	200-250'
From adjacent property line	100'	100'	100'
From a surface water body	100'	100'	100'
From ground surface to bedrock	5'*	5'*	5'*

* Current State of Connecticut practice followed for siting solid waste land disposal facilities.

Table 15 (continued)

Leaf Compost Guidance Summary

Parameter	Method		
	Leaf Pile	Windrow and Turn	Forced Aeration
From ground surface to seasonal high water table (highest seasonal level)	5'*	5'*	5'*
3. Compost process time	2-3 years	Varies with frequency of turning windrows, 6-12 months	4-6 months
4. Curing time (following compost process)	Not Applicable	1 month (min)	1 month (min)
5. Odor generation	Can be high at time of initial pile disturbance.	Some odor potential when pile is first disturbed; proper management will reduce or eliminate this potential; decreases with pile turning frequency.	Minimal problem if the system is properly designed, installed and operated.
6. Equipment needs	Front end loader daily during leaf collection period.	Front end loader daily during leaf collection period and when windrows are turned. 3 or 4 foot stem type thermometer. For large leaf composting facilities, evaluate the use of specialized mechanical equipment for turning windrows.	Front end loader, tub mill grinder, blower type fan, temperature and timer switch controls, plastic piping (both solid and perforated lengths needed), 3 or 4 foot stem type thermometer. Adequate electrical capacity. Optional leaf shredder.

Table 15 (continued)

Leaf Compost Guidance Summary

Parameter	Method		
	Leaf Pile	Windrow and Turn	Forced Aeration
7. Water supply	Required for fire control and wetting of leaves. Up to 45 gals/cu yd.	Required for fire control, wetting of leaves; can use water hose or a portable water tank source having water spray capability. Up to 45 gals/cu yd. large operations may require on-site water	Required for initial wetting of leaves (see windrow) and for fire control. Up to 45 gals/cu yd.
8. Operational	Nothing done to leaf piles; may combine leaf piles after initial pile shrinkage. Maintain height of at least 6 feet.	Combine windrows after pile shrinkage occurs (1 or 2 months after their formation). Turn windrows as indicated by temperature and moisture data.	Blow air through the pile. An organic material such as wood chips, sawdust, or compost is used as a pile cover for insulation. The frequency and time of aeration is by timer switch or temperature controlled.
9. Comments	End product quality may limit marketability; shredding will approve appearance.	Acceptable compost quality; screening of compost will give a more uniform product.	The field experiment data available for this application is rather limited. Method has been used successfully where leaves have been composted with sewage sludge. (Greenwich CT).

(17:10)

Minimal-Level Technology. This is "a very low-cost approach to leaf management, requiring more land, but less labor and capital, than other composting technologies" (41:7). A large buffer zone is required since the compost pile will most likely become anaerobic and produce foul odors.

This level of technology is similar to the passive leaf pile method. Both require less effort but a much longer time period to produce the finished product. To improve the quality of the finished product, a final screen could be used to separate the usable compost product from the clumps of uncomposted material. This unusable material could then be reincorporated into the compost pile until it is decomposed.

Low-Level Technology. Just as windrow and turn, this level of technology is the most common method of composting yard trimmings (41:7). Low-level technology parallels windrow and turn but limits the turning equipment to front-end loaders. The overall objective is to create windrows large enough to have sufficiently high temperatures to decompose the material while at the same time keeping the windrows small enough so anaerobic conditions do not occur (40:11). The combining of windrows and proper frequency of turning will meet this objective.

Windrows should be combined after the first month since volume reduction initially occurs at a rapid rate. Windrows are then turned every

three to four months, producing a finished product in about 16 to 18 months (41:8).

A smaller buffer zone is required since the frequency of turning will decrease the possibility of odor problems. The land area required for the actual composting process is larger due to the formation of windrows. Not including the buffer zone, the compost facility will require a land area of about one acre per 3,000 to 3,500 cubic yards of collected yard trimmings (41:8).

Just as for minimal-level technology, a final screen can be used to increase product quality.

Intermediate-Level Technology. This level of technology is also similar to the windrow and turn method. The major distinction between intermediate-level and low-level is that intermediate-level employs the use of windrow turning machines. Windrow turning machines can straddle the windrow or can be pulled by a front-end loader down each side of the windrow.

Since turning machines are used, the total time to produce a finished product is reduced to four to six months. The windrow sizes are limited to smaller dimensions to accommodate the machines; therefore, the required land area for composting may be greater. The capital costs for these machines can also be higher than for the equipment required for lower level technologies (41:8).

High-Level Technology. This level of technology incorporates a forced aeration system with intermediate-level technology operations.

> Initially, the leaves are wetted. Nitrogen may be added to further accelerate the composting process. Windrows, at least 10 feet high by 20 feet wide, are then formed. They are aerated by forced pressure blowers at the base which are controlled by a temperature feedback system. After composting for 2-10 weeks under these controlled, optimal conditions, the automated system is removed. (41:9)

The windrow turning machines are then used to allow composting to be completed in three to four months. "As a precaution against release of odors during initial windrow formation, a buffer zone similar in size to that required for low-level technology composting is recommended" (41:9).

Other organic material can be composted using this type of technology. Food waste and paper waste can be incorporated into the process although at this time many companies and communities have chosen not to add these wastes.

Table 16 presents some of the basic differences in the processing methods but does not include minimal-level technology. However, Table 17 includes minimal-level and explains the processes based on different criteria.

Table 16

Yard Waste Processing Technology Summary

	Low Tech.	Medium Tech.	High Tech.
Process Retention Period (1)	Long	Short	Very Short
Buffer Zone (2)	Large	Small	Small
Quality of Product (3)	Unrefined	Refined	Highly Refined
Capital Cost	Low	Moderate	High
O&M Cost	Low	Moderate	High

(1) Long (Approximately 2 to 5 years), Short (Less than 1 year)
(2) Large (In excess of 500 yards), Small (200 to 500 feet)
(3) Unrefined (Product contains rocks, pebbles, sticks, and twigs)
Highly refined (Product is clean humus, particle size less than 0.05 inches)

(29:31)

Table 17

Appropriate Leaf Composting Technology

Total Space*	Buffer Zone	Time**	Technology	Cost
Abundant	Wide	Long	Minimal	Very Low
Adequate (1)	Moderate	Moderate	Low-level	Low
Adequate (2)	Moderate	Short	Intermediate	Moderate
Little	Moderate	Short	High-level	Moderate

* Including buffer zone.

** Appropriate times: long (3 years), moderate (16-18 months), short (6-10 months).

(1) Approximately 1 acre per 3,000 cubic yards of leaves, plus buffer.

(2) Probably more than 1 acre per 3,000 cubic yards.

(40:24)

VIII. Composting Equipment

Introduction

The equipment required to operate a compost facility will vary depending on the collection method, level of technology chosen for the composting process, size of the facility, and desired end use. There are several stages in the composting process where equipment is necessary, and the type and cost of equipment will vary. Appendix I lists different types of equipment and the average costs of each. In addition, Appendix J lists equipment manufacturers and representatives for various composting equipment. The major types of composting equipment are discussed in the following section.

Front-end Loaders

"A front-end loader is the single most important piece of equipment for yard waste composting" (29:34). For smaller facilities, the front-end loader may be the only piece of equipment necessary. The front-end loader is involved in the process from the beginning with moving incoming wastes, then combining piles, and finally moving the finished product. The general requirements needed in a front-end loader are as follows.

> A loader rated for two cubic yards of gravel should be able to handle a four cubic yard, light material bucket. A typical loader with self-leveling (automatically returns the bucket to ground level) and a thirty second cycle time should be able to move 480 cubic yards per hour and operate about 6 hours per day or 130

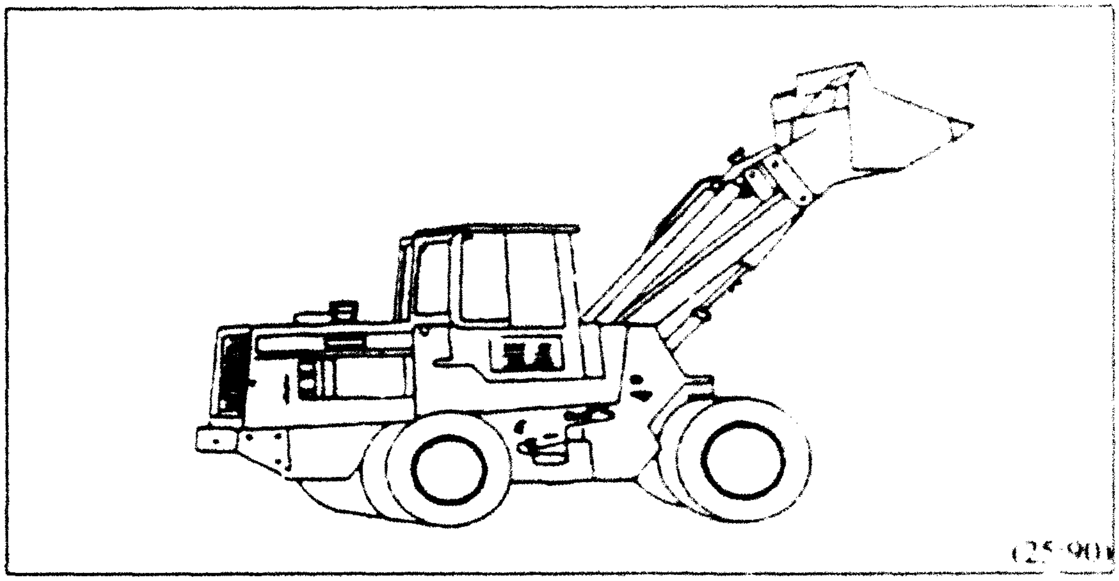


Figure 15. Front-end Loader

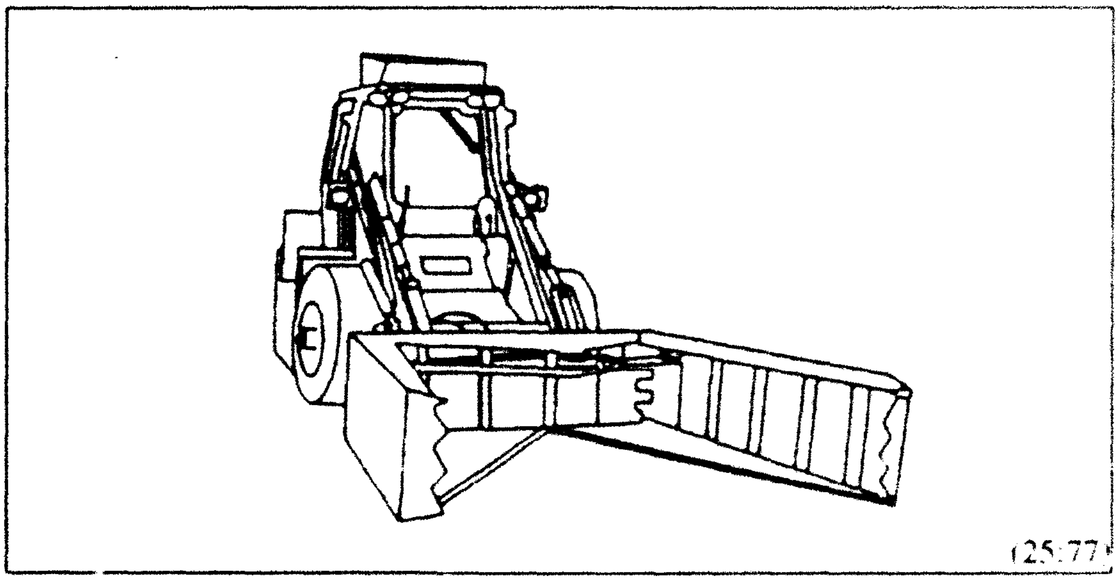


Figure 16. Front-end Loader with Claw Attachment

hours per month. It may be useful to purchase a claw attachment for loading and moving woody wastes. (29:34)

Table 18 gives an example of the time required to operate a front-end loader at a site that does not utilize windrow turning machines. The assumptions are specific and will cause variations in the time requirements if these conditions are not met.

Windrow Turners

Windrow turning machines decrease processing time and are more economical for larger sites.

> When yard waste volume is expected to reach 25,000 or more cubic yards annually, municipalities will find it worthwhile to explore the possibility of purchasing a compost windrow turning machine. (3:75)

Larger models are self-propelled and straddle the windrows (up to 18 feet wide and 7 feet high). Smaller machines are side-mounted or pulled behind front-end loaders and require two passes through the windrow.

> Some side-mounted units have their own engine for driving the aerating mechanism and only need to be pulled by the tractor or loader. Other side-mounted units must be attached to a 3 point tractor hitch and driven off the PTO [power take off]. These may require a tractor or loader with a larger engine of 100 horsepower or greater. (29:34)

"Depending on the size of the machine, turners can process between 700 and 3,000 cubic yards per hour" (29:34).

> Advantages to windrow turners are that they thoroughly aerate and mix the material, turn more yards per hour than front-end loaders and usually produce a compost with superior texture. They are especially suited for high volume facilities. Disadvantages

Table 18

Typical Schedule and Generalized Manpower and Equipment Requirements for a Moderate Sized (15,000 yd) Low-Level Technology Leaf Composting Operation

	Schedule		Time Required	
Operation	Months	Flexibility	Front-end Loader	Laborer
Prepare site	Sept-Oct	Yes	2 days	2 days
Form windrows	Late Oct-Dec	No	6 weeks	6 weeks
Combine	Dec-Jan	Yes	2 weeks	---
Turn	March-April	Yes	1 week	---
Form Curing Pile	Aug-Sept	Yes	1 week	---
Shred (optional)	March-May	Yes	4 weeks	4 weeks

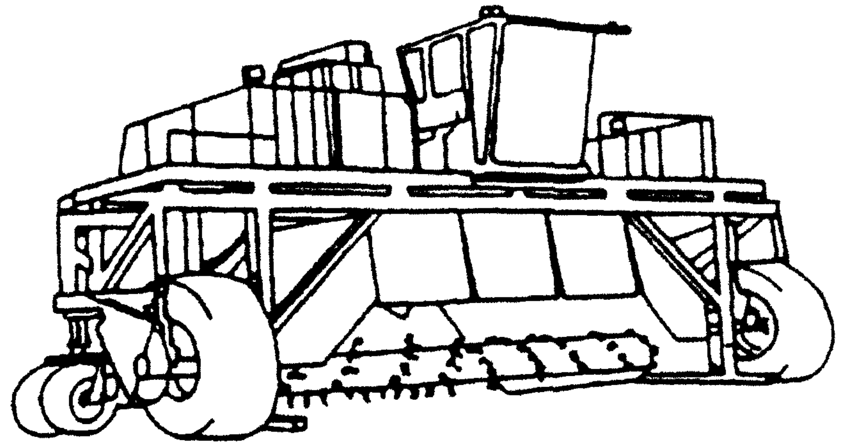
General Assumptions:

(1) site has been prepared to allow necessary truck access and loader operation under any expected weather and ground conditions.
(2) leaves delivered in bulk (not bagged).
(3) adequate supply of water.
(4) daily supervision by a responsible person during periods of activity, regular checks at other times.
(5) manpower required for distribution of finished compost not considered.

Other equipment such as a grader may be required.

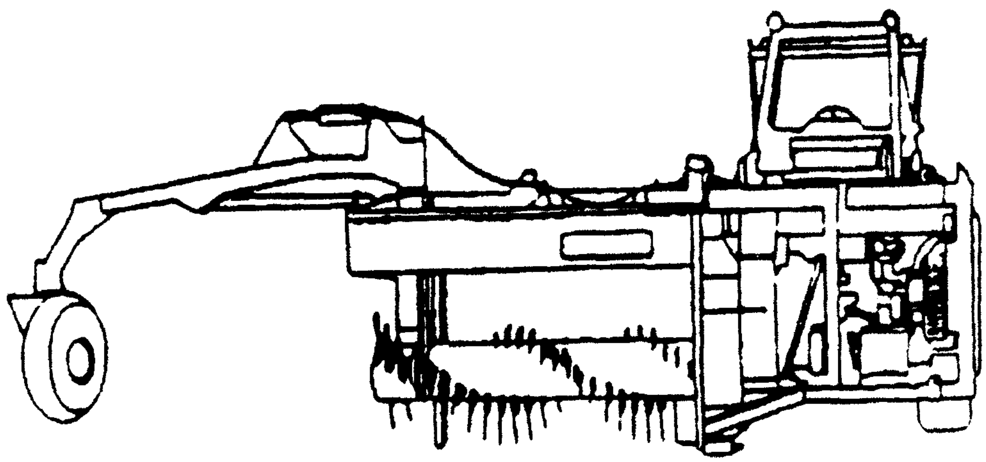
Wetting leaves - average of 20 gallons per cubic yard.
Windrow size - 6 feet high by 12-14 feet wide.
Aisles - 1-2 feet wide for pairs of windrows, 12-16 feet wide between pairs.
Avoid compaction.

(40:25)



(25:95)

Figure 17. Windrow Turner - Straddling Model



(25:95)

Figure 18. Windrow Turner - Side-mounted Model

are that turner design usually limits windrow dimensions to a maximum of 5 to 7 feet high and 14 to 18 feet wide at the base,

they usually require level surfaces to operate efficiently, and some are difficult to move from site to site because of their size. (29:34)

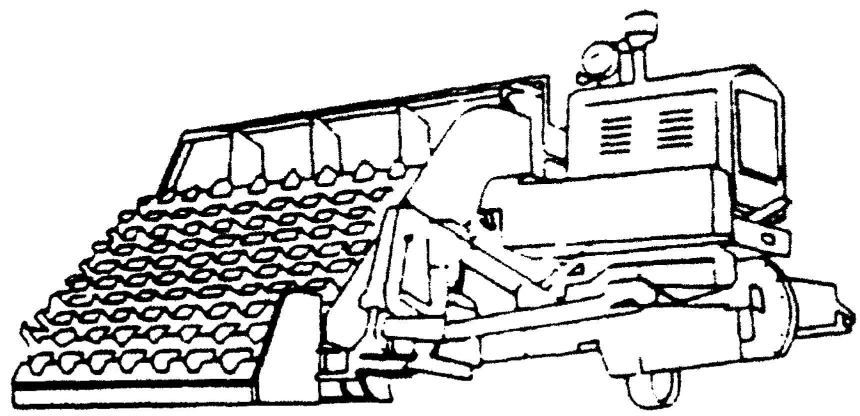

(25:95)

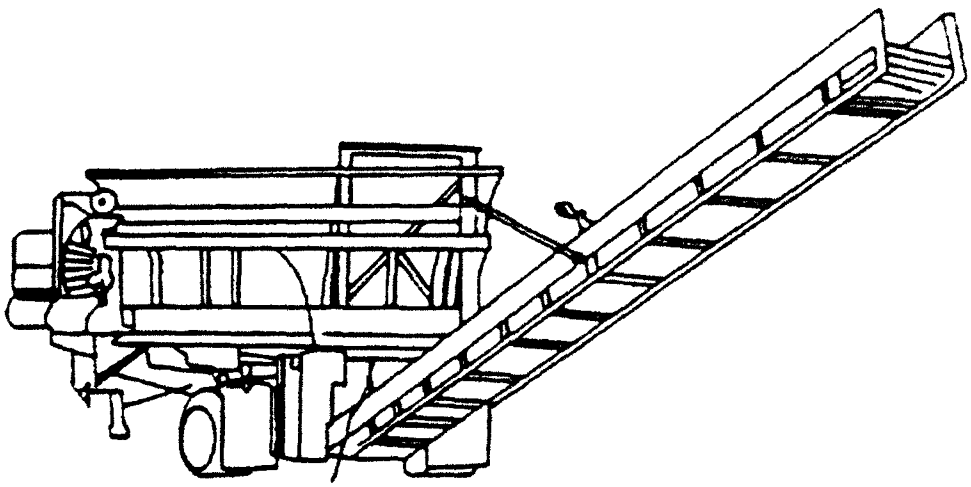
Figure 19. Windrow Turner - Elevating Face Model

Since the size of the windrows are limited, the colder winter climates of northern regions could have an adverse effect on the temperature requirements for microbial activity (50:4).

Turning machines are efficient but could require a much larger investment compared to front-end loaders. Options for using a turning machine include leasing, contracting with a compost management firm on a per-hour basis, or sharing the cost and use with another facility.

The maintenance requirements for these machines include replacing the

flails or teeth on a regular basis at approximately $1,000 per set (7). Other maintenance is similar to that required for large pieces of equipment.



(25:91)

Figure 20. Tub Grinder

Grinders and Shredders

The purpose of grinders and shredders is to reduce the size of the material to aid decomposition and to improve the size distribution of the final product. "High torque shear shredders, hammermills and tub grinders are the three categories of grinding and shredding equipment used for yard waste composting" (35:89). Shear shredders reduce the size of the material through the use of knives.

> The conveyor drops the materials onto a belt that undergoes a continuous raking action to shred and aerate the load. By the use of adjustable, variable sweep fingers, oversized pieces are forced

> back for further shredding while unshreddable material, such as sticks, stones, metal, and glass are rejected and discharged through a trash chute. (35:89)

A hammermill employs free swinging metal hammers that are mounted on a rotating shaft. As the hammers rotate, the material is crushed until it can discharge through the small openings between hammers (35:90). Various size hammermills can accept material as large as stumps.

Grinders crush the material using a rotating tub-type intake system.

> The rotation moves materials across a fixed floor containing hammermills that shear the material. As material is ground, it is forced through a screen and then conveyed into standing piles or into a transfer vehicle. (35:90)

Screeners

Screeners improve the quality of the finished product by performing two important functions: 1) removing contaminants such as plastic bags, rocks, and debris; and 2) separating the compost into various sizes for distinct end uses such as a soil amendment or mulch.

Vibrating screens and trommel (rotating) screens are used to complete these tasks. Vibrating screens use a shaker table and interchangeable grates, each allowing a particular screening size. Material is loaded into a hopper that discharges it onto the vibrating screen. As the screen vibrates, the fines fall through to a collection conveyor and the larger particles are shaken down the inclined screen and emptied onto a separate conveyor.

A trommel screen is basically a large cylinder with holes that rotates and separates materials into two or more sizes. The fines fall through the holes in

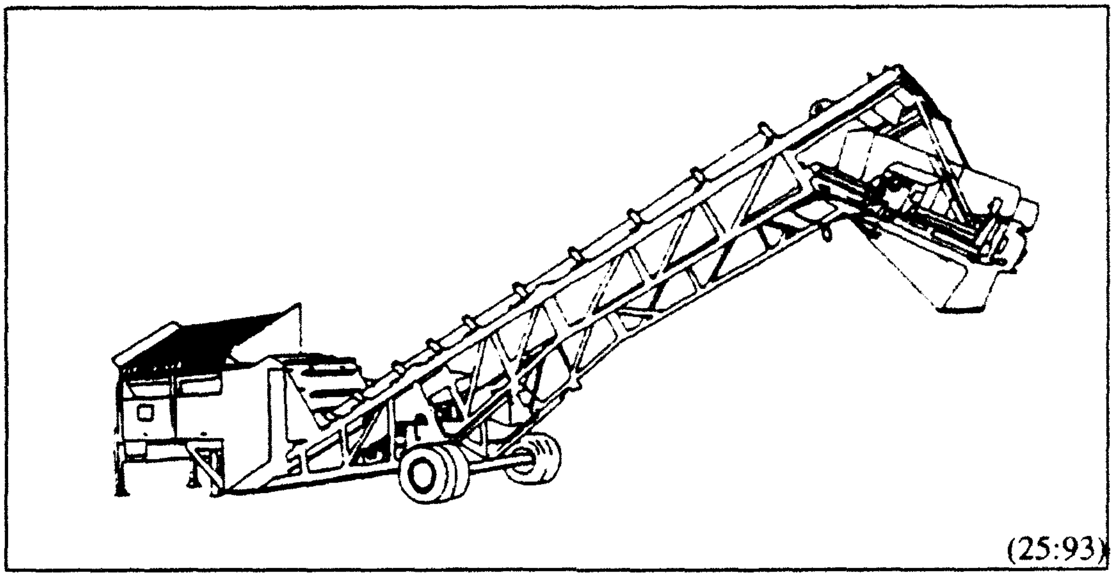


Figure 21. Shaking/Vibrating Screener

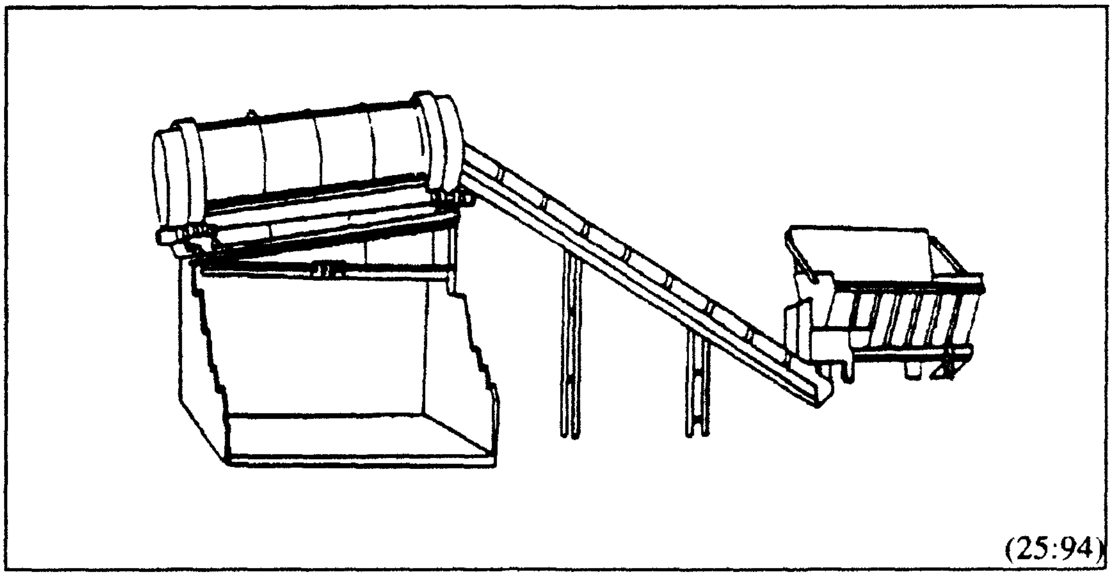


Figure 22. Trommel Screen

the cylinder as the larger particles fall out the end. "Trommels are preferable since they often have brushes for self-cleaning" (29:35). The throughput is increased with the use of a trommel compared to a vibrating screen (7).

Monitoring Equipment

Monitoring equipment is used to control the physical, chemical, and nutritional factors that affect composting. Temperature is the most common factor to monitor. "Thermometers may be the only instruments needed to monitor composting operations. A thermometer with a three to four-foot stem and 0-200°F or 0-100°C range is an essential item" (35:85). Windrows are usually turned according to temperature levels. Figure 23 shows proper placement of a temperature probe for monitoring windrow temperature.

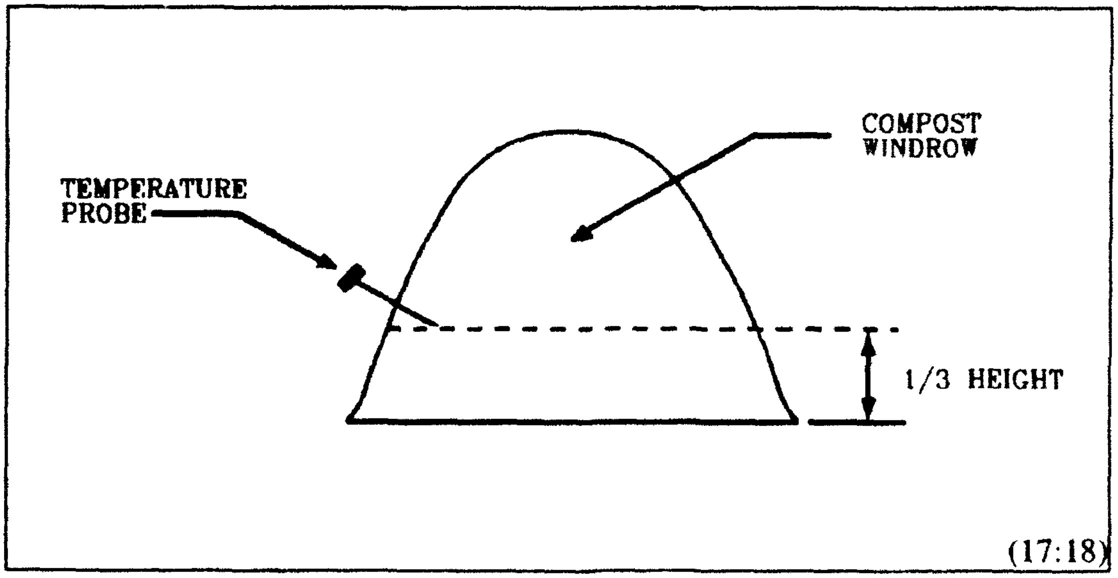


Figure 23. Temperature Measurement Technique

Moisture content is also a factor that can be monitored. A sample of material is weighed and then heated to over 220°F and weighed again. The percent moisture is determined by subtracting the dry weight from the initial weight and dividing this figure by initial weight.

IX. Practical Aspects of Composting

Introduction

In a scientific process such as composting, theory and practice do not always coincide. The published material on composting completely describes the theoretical aspects of the process. However, the actual operation of a compost facility can vary from the theoretical process. To fully understand the composting process, it is imperative to visit an actual composting operation. Site visits provide a hands-on knowledge of the practical aspects of composting, allowing a comparison of practice and theory. Many of the concepts in the literature are not fully applied in the field.

Eight facilities were visited during this research process. Sites were chosen on the west coast and the east coast to provide some diversity in local environment and cultural practices. Four of the eight sites are in California, Oregon, and Washington and the remaining four are in North Carolina, Maryland, and New Jersey.

The following summaries provide specific data about each of the sites. Each summary addresses site location, ownership, compost process method, type of waste composted, and general size and layout of the facility. A discussion of the compost process from receipt of incoming material to production of the finished product provides an overall picture of each facilities operation.

Site: McFarlane's Bark & Compo-Stuff, Portland, Oregon (28)

Ownership: Privately owned, privately operated

Process: Static Pile

Size: 3-4 acres

Waste Type: Leaves, grass, wood and brush

McFarlane's compost facility is one of two visited in the Portland area and has been operating for several years. It is well established and produces a quality end product which is in constant demand by many local citizens and companies.

The site receives incoming material from both private citizens and contract haulers. Disposal fees at the site range from $28.00 to $35.00 per ton of mixed yard waste which is considerably lower than the $68.00 per ton tipping fee charged at the landfill. This price difference provides an incentive to local landscapers and hauling companies to segregate the yard waste. A truck scale is used to weigh the incoming material.

The composting process consists of one large static pile that covers approximately two acres and is about 40 feet high. The process begins with receipt of the incoming yard debris. Plastic bags are no longer used for waste collection in the Portland area therefore contamination at the site is minimized. Biodegradable paper bags have become common and are readily accepted on site.

Yard waste is received in a variety of sizes and mixtures. Large pieces of wood that would not readily decompose are processed using a hammermill grinder equipped with a shaker table which cuts the wood into pieces small enough to be placed on the pile. Smaller branches and prunings are processed through a tub grinder. A front-end loader and bulldozer are used to push the incoming material to the top of the pile. The final product is removed from the bottom of the opposite end of the pile.

The composted material is moved from the static pile to a smaller pile to stabilize before final screening. A trommel screen is used to separate the materials that are too large to be used as compost. The larger materials are placed back into the pile and the smaller ones are graded for selling.

The temperature within such a large pile of compost reaches levels well over 200°F. Spontaneous combustion has caused a fire on several occasions. Water is available on site and is added to increase the moisture level near the surface, however it does not penetrate to the core of the pile.

The final compost product is available in three grades: fine, medium, and course. The fine grade consists of materials smaller than 5/8 inch and is marketed as an alternative to bark dust. The medium grade contains some fines but also includes material up to two inches and is sold as a soil amendment. The course grade is the overs from the fine and medium grades and includes materials larger than two inches.

The final product is tested for metals content and carbon to nitrogen ratio by the Metropolitan Service District of Portland to insure compliance with local standards. The demand for the product is increasing at a rate faster than the material can be processed.

Site: Grimm's Fuel Company, Portland, Oregon (14)

Ownership: Privately owned, privately operated

Process: Static Pile

Size: approximately 30 acres

Waste Type: Leaves, grass, wood and brush

Grimm's Fuel company manages a wood fuel operation and a separate yard waste composting facility. It's operation has steadily grown with the demand for landfill disposal reduction and is now capable of composting all yard waste generated in the Portland area. The site is configured to manage two distinctive waste streams: yard waste and wood waste. An estimated 200,000 cubic yards of yard waste (leaves, grass, brush) and 100,000 cubic yards of wood waste (pallets, construction waste, stumps, trees) will be processed in 1992. The material is delivered to the site by contract haulers, landscapers, and private citizens.

The facility is located in a rural area with room for expansion. An office is on site along with a separate maintenance facility to make any necessary equipment repairs. Although it is not in use, the site is also equipped with a forced aeration composting system.

A truck scale is used to weigh the incoming material. The nearest landfill charges $56 per ton of mixed waste while Grimm's charges $20 per ton

for yard waste. This gives individuals and companies a cost savings but requires the materials to be separated from the municipal waste stream.

The process begins with separation of the waste materials once they arrive at the site. The wood materials are chipped separately and sold as fuel chips. The yard waste is processed through a static pile composting operation. All incoming yard waste is first processed through a large hammermill grinder for initial volume and size reduction. The ground material is then formed into a static pile and allowed to decompose for three months. After three months, the partially decomposed material is ground again and placed back in the static pile for an additional month. Next the material is processed through a trommel screen to separate the composted product from the larger, not fully decomposed materials. The larger materials are placed back onto the pile to complete decomposition. The screened compost product is moved to a final stabilization area and allowed to cure for six additional months.

The finished product is available in a variety of grades for specific end uses. It is tested by the Metropolitan Service District of Portland to ensure compliance with local standards.

Site: Cedar Grove Compost Company, Seattle, Washington (37)

Ownership: Privately owned, privately operated

Process: Windrow

Size: Approximately 25 acres

Waste Type: Leaves, grass, wood and brush

The Cedar Grove Compost Company has been producing compost from yard waste since 1989. Approximately 300,000 cubic yards of yard waste was processed by Cedar Grove in 1990 and 1991. Yard waste from Seattle's "Clean Green" program is processed at the facility to produce "Cedar Grove Compost", a high quality soil amendment. Cedar Grove accepts only yard wastes that are collected at residences or deposited at transfer stations. All yard waste is inspected for trash and painted or treated wood contamination.

The incoming material is delivered by commercial haulers who pay $30.00 per ton to dispose of the yard waste at Cedar Grove. This represents a savings of approximately $28.00 per ton of waste when compared to the $58.00 per ton charged at the local landfill. The facility is equipped with a truck scale for weighing incoming trucks.

The main composting area is divided into two sections, 1) a windrow processing area, and 2) a static pile curing area. The windrow area sits on an asphalt and concrete pad. The pad provides a solid surface on which to work the incoming materials and windrows. The incoming materials are delivered to

this area and processed through a shredder for initial volume and size reduction. The shredded material is then placed in windrows about six feet high, 15 feet wide at the base, and approximately 200-300 feet long. A Scarab windrow machine is used to turn the windrows. The compost remains in windrows for eight to ten months.

The static pile area is used as a staging and curing area for the composted material. Compost in this area is moved in from the windrow area to allow for stabilization. After approximately eight months in this area, the compost is processed through a trommel screen and moved to the final processing area.

Cedar Grove produces three grades of compost.

1. Fine: less than 7/16"
2. Medium: 7/16" - 3/4"
3. Coarse: 3/4" - 1 1/2"

The fine grade can be used as topsoil amendment and as a nursery mix amendment. The medium grade can be used as mulch for trees and shrubs and as a nursery mix amendment. The coarse grade can be used as a mulch for reclamation planting or erosion control.

The Cedar Grove facility also has a bagging operation. The finished compost is bagged in one cubic foot bags and marketed as Cedar Grove Compost. Each of the three grades of compost is available bagged or by bulk

(one cubic yard or greater). This facility produces one of the best finished products examined.

Site: Zinker Road Construction and Demolition Landfill, San Jose, CA (38)

Ownership: Privately owned, privately operated

Process: Windrow

Size: Approximately 20 acres

Waste Type: Leaves, grass, wood and brush

This composting facility is located on the site of a construction and demolition landfill. There are three other municipal solid waste landfills in the San Jose area but yard waste composting is accomplished only at this facility. The site is isolated from residential areas and is secured with buffer zones and fencing. The compostable materials are separated from the incoming waste stream on site and the remaining waste is divided into concrete, wood, trash, heavy and light metals, and tires.

Approximately 30,000 to 40,000 tons of yard waste is received at the site per year. This averages to about one cubic yard per household per year.

Landfill tipping fees at some facilities in this area of California are as low as $11.00 per ton of municipal waste. As a result, the city of San Jose supplements the Zinker Road composting operation $20.90 per ton of yard waste. As a benefit, the city receives 20 percent (about 7,000 cubic yards per year) of the end product to use for city facilities and projects.

As the incoming yard waste is received, it is placed in a large holding pile where it remains for at least one month prior to processing. This pile

contains all types of yard waste, including grass clippings. Because of the size of the pile, the composting taking place near the bottom is anaerobic and odors are noticeable when the materials are moved to the screening area.

Materials from the holding pile are separated into two sizes by a disk screen equipped with a shaker table. The larger materials (i.e. large branches and limbs) are moved to a chipper where they are chipped for use as a mulch or fuel. The smaller materials are moved to the windrow area for composting.

The composting materials remain in the windrows for nine to twelve weeks. During this time, the windrows are worked with a turning machine as conditions dictate. The turning breaks-up and rebuilds the windrows, providing both size reduction and aeration; thus, enhancing the composting process. The length of time in the windrows is reduced due to the initial decomposition which takes place in the large holding pile. After composting is completed, the product is processed through a trommel screen with 1/4 inch separation. The fine grade (1/4 inch and smaller) is sold as a soil amendment. The larger product (larger than 1/4 inch) is sold as mulch.

Site: Middlebush Compost Inc., Somerset, New Jersey (49)

Ownership: Privately owned, privately operated

Process: Windrow

Size: 25 acres

Waste Type: Leaves

The Middlebush facility services several communities around the Somerset area. The site is located in a rural setting on approximately 25 acres with few residences nearby. An office is present on site. The design and layout of the site was approved according to the New Jersey State composting guidelines. The entire site is underlaid with a permeable geotextile matting that improves water percolation and provides a stable surface on which to process the incoming materials and work the windrows.

Middlebush accepts only leaves for composting. The isolation of the facility from the communities it serves necessitates use of transfer stations for collecting the leaves. The leaves are delivered to Middlebush by both local landscape companies and contract haulers.

The local landfill tipping fee of $125.00 per ton provides great incentive for private composting operations. Middlebush charges $30 per ton for incoming leaves. This figure appears to be low when compared to the landfill charge, however it is as high as the market will support because New Jersey now allows farmers to land farm the yard waste instead of requiring composting

using more modern methods. Farmers are capitalizing on this opportunity and are charging small fees to haulers to allow dumping of yard waste on their property. The farmers simply turn the leaves and incur few additional costs.

Middlebush's compost process begins with the incoming material being placed directly into windrows. A scarab turning machine is used to mix and aerate the windrows. A front-end loader is used to combine the piles and transfer the composted material to the final screen. Once the leaves have composted, a power screen is used to separate the composted product from the overs. The overs are piled and sent to the landfill or rerouted through the screen.

The end product is sold for \$12.00 per yard if screened and \$6.00 to \$8.00 per yard if not screened. The estimated cost of screening the material is \$3.00 to \$4.00 per cubic yard.

The temperature of the windrows are checked twice a week and the pH and moisture level are checked weekly. There are no odor problems at the site and leachate is well controlled. A unique drainage system was designed using straw bales as barriers around a sand and gravel field that controls runoff. A sand bed measuring 30 feet wide by four feet deep by 100 feet long retains the water as it percolates. PVC pipes are used to evenly distribute the incoming flow and the adjacent property does not incur any flood damage or excessive flows of water.

Future expansion of the site will include composting grass and possibly other organic substances that will readily compost in a windrow.

Site: Prince George's County, Maryland (16)

Ownership: Publicly owned, privately operated

Process: Windrow

Size: 47 acres

Waste Type: Leaves and grass

This facility services the entire Prince George's County. It is located adjacent to a wastewater treatment plant and occupies a lighted concrete pad. It is secluded from all private residences and fenced for security. Maryland Environmental Services (MES), a private company, operates and manages the site.

Over 70,000 residents contribute to the compost operation. Municipal haulers, the county, and landscapers are allowed to drop off material. Local citizens must dispose of their yard waste through one of these sources. The county collects leaves weekly using a vacuum truck system. A separate collection truck is used to pick up bags of yard trimmings on a year round basis. There is no charge for bringing the material to the site although the trucks are weighed for information and record keeping. Wood waste is accepted separately and is not mixed with the leaves and grass during the compost process. The local landfill tipping fee is $62.00 per ton of which $10.00 is allocated for the county's recycling and composting program.

The final product is marketed in three grades. "Leafgro" is the finest grade, consisting of composted grass and leaves, and is sold to nurseries and landscapers. The next grade is sold as mulch and consists of wood chips mixed with compost. The third grade is chipped wood and can be used as mulch or for land reclamation and erosion control.

Because the site is paved, a sedimentation pond is required to control runoff and leachate. The pond is lined and is regularly tested for metals to comply with local standards. The only complaints received at the site are related to odor problems occurring in the spring. This is due to the incoming grass which has become anaerobic before arriving at the site.

The process is very well managed. Incoming material is weighed on a truck scale at the receiving station. Next the leaves and grasses are dumped into a Malin grinder for shredding into smaller pieces. A conveyor moves the material to a trommel screen which is used mainly for separating the large pieces of wood and contaminants from the compostable fraction. This step eliminates most of the plastic bags and other non-compostable materials.

Once the finer material is screened, it is moved to the windrows using 100 cubic yard, live floor trailers. The windrows contain up to 1000 cubic yards each and the moisture content, temperature, and oxygen levels are consistently monitored to insure a proper rate of decomposition. Windrows are turned every two weeks with a Scarab turning machine, which is capable of

turning windrows 18 feet wide and seven feet high. During the spring, when large amounts of grass are received, the windrows are turned several times a week to guard against anaerobic conditions. As the piles decompose and decrease in volume, front-end loaders are used to combine the piles and mix in grass when necessary.

Once the piles have sufficiently decomposed, another screen is used to separate the final product into the various grades. The overs are routed back into the composting piles. The total process, including curing time, takes about nine months to complete.

Site: Montgomery County, Maryland (7)

Ownership: Publicly owned, privately operated

Process: Windrow

Size: 46 acres

Waste Type: Leaves and grass

This facility services the entire Montgomery County. It is located in a rural setting and occupies a lighted concrete pad. It is secluded from all but a few residences and fenced for security. The site is equipped with a scale, office and maintenance facility. Maryland Environmental Services (MES), a private company, operates and manages the site.

The site receives leaves and grass from two transfer stations located 20 and 25 miles away. Municipal haulers, the county, landscapers, and local citizens drop off material at the transfer stations. The yard waste is weighed at the transfer station and a tipping fee is charged. The wood and brush debris received at the transfer station is not transported to the composting site for processing.

The windrows are formed in three areas, each of which is serviced by a retention pond. The retention ponds have a total capacity of about 13.2 million gallons. The facility's NPDES permit requires monthly testing of BOD and COD.

A total of 120 windrows can be accommodated by the three areas with each windrow 300 feet in length. The average capacity for the site is about 90 windrows which account for 20,000 tons per year of leaves and grass. Leaves comprise 16,000 tons of the mix while the remaining 4,000 tons is grass. The county is expected to exercise a ban on landfilling yard waste in the near future. As a result, they expect segregated yard waste to increase to approximately 80,000 tons per year.

The process begins when the leaves and grass are placed in the windrows by the trucks from the transfer station. The windrows are formed using front-end loaders and a scarab turning machine is used to mix and aerate the windrows. For leaves, the turning rate is once per month. When grass begins to arrive on site, the rate is increased to three times per week to avoid anaerobic conditions. Leaves are mixed with grass at a ratio of 2:1.

The grass is placed in a large windrow and mixed with the scarab. The grass pile is then divided into two piles to be mixed with two leaf piles. A front-end loader is used to cascade the leaves over the grass before the scarab mixes the pile again. It takes approximately two hours to combine the leaves and grass into one 300 foot long pile. This process insures a homogeneous mixture of grass and leaves.

Windrows continue to be mixed and combined using the turning machine and front-end loaders until the composting process is complete. One ton of

incoming material decomposes to approximately one cubic yard of usable end product. Once composted, the material is moved to a large pile that averages about 20,000 cubic yards (one years supply). The material cures in this pile until ready for final screening.

Before screening, the composted material is dried to enhance operation of the power-screen. To dry the material, it is spread over a 200 by 300 foot area to less than six inches thick. A manure spreader or harrow is used to evenly distribute the material. It takes about two to three hours for the material to adequately dry. Once dry, a front-end loader piles the material and places it in the final screen. The power-screen is equipped with a shaker table with one inch clearances. The overs are piled for rescreening or final disposal in a landfill and the fines are ready to be distributed.

The entire process requires about 15 months to complete. The leaves that arrive in the fall are ready by spring, following the 15 month process. Local landscapers purchase most of the final product which can be delivered throughout the county.

Site: Seymour Johnson Air Force Base, North Carolina (22)

Ownership: Publicly owned, operated by the United States Air Force

Process: Windrow

Size: 2 acres

Waste Type: Leaves, grass, wood and brush

Seymour Johnson Air Force Base occupies approximately 3,300 acres near Goldsboro, North Carolina. The base employs about 5,500 military and civilian personnel and is also home for a minimum security federal prison camp housing around 650 inmates.

The yard waste compost operation occupies a two acre fenced site on the western end of the base, approximately two miles from the main base functional areas and three miles from the military family housing areas.

The site is managed by the base Civil Engineering Squadron and labor is provided by both civil engineering and the federal prison camp.

Seymour Johnson has actively been composting yard waste since the fall of 1990 and moved the operation to its present location during the fall of 1991. The present site contains seven windrows approximately eight feet high, 15 feet wide at the base, and approximately 100 feet long.

Yard waste collected from both the main base area and the housing areas is delivered to the site and deposited on the end of the windrows. A front-end loader is used to turn the windrows as temperature monitoring dictates. If

required, water is added to the windrows when they are turned. The equipment used at this facility is part of the Civil Engineering Squadron's inventory and is adequate for handling the incoming material, and building and turning the windrows. However, the facility could benefit from the use of a shredder at the beginning of the process.

The composting program was initiated at Seymour Johnson as a desire to do the right thing with regards to yard waste disposal. The modest tipping fee of $14.00 per ton of waste paid by Seymour Johnson, while providing a cost avoidance, does not provide an overwhelming economic incentive. The decision to compost was made with concerns of reducing landfill disposal and improving the environment as major drivers.

The finished product is available in eight to twelve months. The bulk of the finished compost is used by civil engineering in landscape projects across the base. The product is also available to base personnel on a pick up basis.

Summary of Site Visits

The following summaries and analyses of the eight sites visited are presented in tabular form.

Table 19

Summary of Site Visits - Overview

Site	Ownership (Own/Oper)	Process	Size	Waste Type
McFarlane's	Priv/priv	Static Pile	3-4 acres	L/G/W/B
Grimm's	Priv/priv	Static Pile	30 acres	L/G/W/B
Cedar Grove	Priv/priv	Windrow	25 acres	L/G/W/B
Zinker Road	Priv/priv	Windrow	20 acres	L/G/W/B
Middlebush	Priv/priv	Windrow	25 acres	L
Prnc Grge Cty	Publ/priv	Windrow	47 acres	L/G
Mont County	Publ/priv	Windrow	46 acres	L/G
SJ AFB	Publ/Publ	Windrow	2 acres	L/G

L - leaves, G - grass, W - wood, B - brush

Table 20

Summary of Site Visits - Process Characteristics

Site	Compost Technology	Composting Time	Grind/Screen
McFarlane's	Static pile	3 - 5 Years	G/S
Grimm's	Static pile	12 mths	G/S
Cedar Grove	Windrow/Turn	18 mths	G/S
Zinker Road	Windrow/Turn	4 mths	G/S
Middlebush	Windrow/Turn	15 mths	S
Prnc Grge Cty	Windrow/turn	15 mths	G/S
Mont County	Windrow/Turn	15 mths	S
SJ AFB	Windrow/Turn	12 mths	None

G - Grind, S - Screen

Table 21

Summary of Site Visits - Process Management

Site	Process Monitoring	Runoff Control	Buffer Zone	Product Testing
McFarlane's	None	None	Small	Yes
Grimm's	None	None	Small	Yes
Cedar Grove	None	Ditches/ Ponds	Large	Yes
Zinker Road	None	None	Large	Yes
Middlebush	T/M	Sand filter area	Large	Yes
Pmc Grge Cty	T/M	Ditches/ Ponds	Large	Yes
Mont County	T	Ditches/ Ponds	Large	Yes
SJ AFB	T	None	Small	No

T - Temperature, M - Moisture

X. Research Analysis and Recommendations

Research Method

The research followed, with few changes, the methodology outlined in Chapter II. The planned method for meeting the research objectives was to study the literature, visit composting facilities, and interview composting managers.

Literature Review. The literature review included a comprehensive review of books, journals, and state guidance manuals. Computer databases were not used as extensively as first assumed because most of the information available was on the broader subject of pollution prevention and not on the specific issue of composting.

Site Visits. Site visits provided the information needed to support and strengthen the views and suggestions found in the literature. The visits offered an excellent opportunity to gain first-hand knowledge of actual field practices. Although only a few sites were visited, each contributed a unique understanding of the composting process and of what is actually being practiced throughout the United States.

Personal Interviews. Personal interviews with municipal compost managers and site managers provided practical knowledge of the composting process. Managers of composting sites provided details on the specifics of the

overall management of the composting process including collection, contracting with haulers, and marketing the finished product. The information from the interviews verified and provided credence to what was learned at the compost facilities.

Both site visits and personal interviews were undertaken to bridge the gap between the strictly scientific data found in the literature and the practical knowledge used in an actual composting operation. Because of the diverse activities and locations of Air Force bases across the United States, an appropriate selection of visits were made that would provide representative settings. The composting opportunities available to Air Force installations correspond closely to those found in municipalities; therefore, the knowledge gained from the interviews and visits is directly applicable to the Air Force.

Findings from Literature Review, Site Visits, and Interviews

The two main bodies of knowledge used to meet the objectives of the research came from the literature review and site visits. Both of these sources provide the essential information to formulate the recommendations for Air Force composting programs.

Technical Issues. The literature provides the necessary technical information about the composting process. Several excellent books, including Dr Golueke's Biological Reclamation of Solid Wastes and The Rodale Guide to Composting, explain in great detail the scientific process of composting. These

books state composting is a strict process with extremely critical controls. The literature also shows composting occurs in nature and has been used by gardeners for years.

Practical Issues. The literature contains technical information and practical insights into the composting process. Many states have developed yard waste guidelines, providing municipalities with the knowledge needed to begin composting operations. These "how to" guides are excellent sources of information and provide specific permitting and planning guidelines tailored to individual states.

Numerous articles are available in professional journals that report on composting. BioCycle: A Journal of Waste Recycling is devoted entirely to composting and bridges the gap between technical and practical issues. It provides insight through case studies and reports on research.

Control Measures. Site visits and interviews provided a practical, simple view of composting. The strict scientific controls may or may not be exercised, depending on the individual facility and the composting method. The control measures used include temperature, moisture content, aeration, turning frequency, grinding, and screening. The facilities that follow established management practices and use more of these controls produce a better end product. Determining which control measures to use depends in part on the quality required in the finished product and on the attributes of incoming materials.

Regulatory Issues. Legislation has increased to the point where municipalities and government agencies must develop composting programs to better manage the entire yard waste stream. Public awareness is growing as environmental issues receive more and more attention. Municipalities are responding to the public and also the legislation by starting an increased number of composting operations. Composting is stressed as a natural alternative to solid waste disposal.

The Air Force has decided to take the leadership role within the Department of Defense in municipal solid waste management. Air Force Regulation 19-4 is a result of this decision.

Analysis of Findings

The remainder of this chapter analyzes the information presented in Chapters III through IX and provides recommendations on composting for the Air Force. The literature review and site visits present unique insights into the understanding of the composting process. Although the literature presented detailed descriptions of the composting operations, site visits offered an examination of simplified, existing practices.

It is important to make a distinction between practice and theory. This is accomplished through an analysis that compares and contrasts the important aspects of the composting process as described by both the literature and visits.

The following factors are analyzed to provide decision makers with information required to successfully design, plan, and implement a composting program.

1. Types of organic waste
2. Types of yard waste
3. Levels of technology
4. Equipment requirements
5. Process management

Recommendations for a composting program applicable to the Air Force are made through analyzing alternatives for each of these factors.

Types of Organic Waste. The literature clearly delineates the boundary of compostable materials. Yard trimmings, food scraps, food processing by-products, non-recyclable paper, and municipal sewage sludge have all been labeled as "compostable" (19:38). Case studies provide evidence that these materials can be composted.

A large number of facilities compost most of the wastes listed above; however, the majority of facilities compost only yard waste. The focus of recent solid waste reduction legislation has been to establish reduction goals and restrict yard waste from landfill disposal. The best management alternative to alleviate yard waste disposal is composting.

Yard waste is naturally amenable for composting while other popular organics such as food and paper require much more effort and expense to compost. However there are exceptions. Certain manufacturing processes, such as food processing, are very specific to one type of waste. In this case, the food

as food processing, are very specific to one type of waste. In this case, the food waste could be composted and would not be subject to the negative impacts associated with combining food and yard waste. Municipalities concerned with composting a mixed solid waste stream from residences and businesses can minimize the concern by composting yard waste only.

Mixed waste composting is gaining popularity as some communities try an integrated waste management approach. Some larger in-vessel mixed waste systems are operating, but with more caution after the Portland, ROCCI incident (refer to page 71).

Choosing the types of waste to compost is one of the basic steps in developing a composting program. Many parameters can be used for determining acceptability of various materials for a composting operation, including:

1. ease of collection and segregation
2. the required level of technology for the composting operation
3. the reliability and volume of the incoming waste
4. public perception
5. permit requirements
6. cost/benefit analysis

The knowledge gained from the literature and site visits establish yard waste composting as a proven technology with very few unmanageable aspects. Yard waste comprises about 17 percent of the municipal solid waste stream (45:ES-5) and is the simplest material with which to begin a successful composting

program. Yard waste composting provides a substantial decrease in municipal solid waste disposal at a relatively minimal start-up cost.

Recommendation #1. The Air Force should immediately begin composting yard waste. Yard waste composting operations can be started quickly and cheaply and present few obstacles to a successful operation.

Types of Yard Waste. Having chosen yard waste as the input material to the composting operation, an understanding of the total yard waste stream is necessary to develop a sound management plan for the facility. An analysis of each component reveals its contributions and impacts to the overall composting process.

Yard waste is comprised of leaves, grass, wood and brush. As stated earlier, leaves are the primary ingredient in the composting process and are always included in a yard waste composting program. Both the literature and site visits prove this to be true. The volume of leaves generated in most communities offers an excellent compost opportunity. In addition, composting leaves provides significant volume reduction of the waste stream entering local landfills (46:81). Leaves contain a high amount of carbon which provides the compost microorganisms with an excellent energy source.

Grass is often added because it balances the characteristics (i.e., C/N ratio, moisture content, etc.) of the leaves and produces better compost in a shorter time period. Grass adds the nitrogen required by the microorganisms for metabolic activity. Composting grass and leaves together requires greater effort

than composting only leaves. However, once the operators of a facility can handle composting leaves alone, adding grass clippings is a natural progression

Wood and brush are compostable and can be included in the compost operation if desired. They present unique handling and processing problems and generally take longer to fully decompose. Therefore, they are not suggested as compost materials. One option for the management of these items is to chip or grind them separate from the leaves or grass and, at the end of the composting process, mix them with composted material to form a medium grade mulch.

Recommendation #2. To provide the best opportunity for successfully recycling yard waste, the Air Force must manage the entire yard waste stream: leaves, grass, wood and brush. The Air Force should compost both leaves and grass together but wood and brush should be handled separately.

Levels of Technology. There are four levels of technology applicable to a yard waste composting program. Although there are advantages and disadvantages for choosing each level, different programs must contend with particular constraints such as time, cost, and product quality.

Minimal-Level Technology. Minimal level composting is basically an above ground landfill operation for yard waste. Very little effort is required (e.g., no turning), but the outcome is poor quality compost with a long decomposition time. Several states recommend that municipalities do not use minimal-level technology as a composting option (40:14; 25:17).

Minimal level can be enhanced through the use of additional equipment. A final screen can be added to segregate the larger undecomposed material from the final end product. This improves the quality of the end product but does not shorten the time required for composting.

Low-Level Technology. Low level composting is the best level of technology for average size communities and most Air Force bases. It employs the principles of "windrow and turn" composting but does not require the extensive capital investments needed in intermediate-level.

A front-end loader is the primary piece of equipment required. Many communities and Air Force bases already have several which could be shared with the compost operation. Larger facilities would require more time on the front-end loader and possibly would need one dedicated to the site.

The windrow and turn composting method increases the decomposition rate of the yard waste and produces a final product in approximately 18 months. Leaves collected in the fall are mixed with the grass from the following spring and the final product is ready one year later.

The transition from low level to intermediate level composting is dependent on the constraints (i.e., availability, cubic yards per hour) of the front-end loader and the volume of incoming material.

Intermediate-Level Technology. Intermediate level composting differs from low level only in the use of turning machines instead of front-end

loaders to mix and aerate the windrows. It is most applicable for larger sites with at least 25,000 cubic yards per year of incoming yard waste (3:75). An option for smaller communities and bases is to combine efforts and build a regional yard waste facility.

The quality of the final product increases substantially with the use of turning machines. The increased quality attracts a broader market of end users (see Table 6 on page 57).

Other optional equipment could include a grinder and/or screener. A grinder is not needed when only leaves and grass are composted, because the turning machine will shred the material as it mixes the windrows. Grinders are most useful for shredding wood and brush but can be used for leaves and grass to augment the composting process.

A final screen can be used to ensure a uniform end product. The larger pieces are separated for further decomposition and the smaller composted material is ready for curing.

High-Level Technology. High level composting, which uses forced air, is not widely used for composting only yard waste. Forced aeration is more beneficial when composting includes a mixture of food or sludge wastes. Materials decompose at a much faster rate when forced aeration is used, the shorter time minimizes possible odor, rodent, and leachate problems.

The cost for high-level composting is much greater and the control and monitoring procedures are more stringent.

A front-end loader is important to this process and is used extensively for material handling from start to finish. A final screen is required to produce a quality end product.

Recommendation #3. The Air Force should use minimal-level technology only when no other options are available. Low-level technology composting should be used at the majority of bases. Intermediate-level composting should only be used when the size of the site dictates the need for windrow turning machines. High-level technology is not recommended for composting only yard waste.

A detailed discussion of the individual steps of low-level technology composting, adapted from the Wisconsin Municipal Yard Waste Composting handbook, is provided in Appendix B.

Equipment. The equipment required to operate a composting site is directly dependent on the level of technology. A front-end loader is always required for yard waste composting. The extent of its use will depend on the size of the site and the volume of incoming materials.

A grinder or shredder is needed if wood and brush are received at the site. Many Air Force bases already have chippers that could be used for this purpose, however large amounts of wood or brush could require larger capacity machines. A grinder or shredder could also be used at the beginning of the process to grind leaves and grass. If this equipment is available, it will enhance

the composting process by reducing the size of the input materials, assisting in retention of moisture, and by creating a uniform compost mixture.

A screen is necessary for achieving a quality end product. The only time a screen is not needed is when the use of the final product is limited to landfill covering, erosion control, and rough landscaping (not noticeable). In most cases, the end product will need to be screened to produce a uniform compost and to segregate undecomposed materials.

> **Recommendation #4. A front-end loader is the one essential piece of equipment for any composting operation. The Air Force should use a front-end loader for moving incoming material, forming and combining windrows, and moving the finished compost. The time schedule of existing loaders needs to be assessed to allocate sufficient time to the composting site. More than one front-end loader may be required to efficiently service the compost operation. If the site is large enough, a turning machine is also recommended.**

> **Recommendation #5. A quality compost product is necessary to ensure acceptance by potential users. The end product must be uniform and clean. The Air Force should use a final screen at all composting sites to obtain a quality end product. This recommendation is not dependent on the level of technology.**

Process Management. Process management consists of the control and monitoring procedures used to better operate a composting site, independent of the level of technology, size, or equipment. Monitoring temperature and moisture content is vital to maintain an efficient rate of decomposition and to obtain pathogen destruction. The temperature of the compost pile should be monitored using long-stemmed temperature probes inserted at various depths to

ensure accurate readings. Moisture content can be estimated by squeezing a handful of the material. For consistent, accurate, moisture readings, an oven test is preferred.

Two additional factors critical to the compost process are C/N ratio and proper oxygen level. The C/N ratio of the composting mass can be tested seasonally by local laboratories or universities to ensure proper mixing of the input materials and to establish a baseline for mixing controls. Oxygen levels can be checked using an oxygen analyzer, however, a much simpler and sufficient way to determine a lack of oxygen is the detection of odors. Odor is caused by anaerobic decomposition. If a compost pile starts to emit foul odors, it needs to be aerated more frequently to return the pile to aerobic conditions.

Proper management of the process also includes windrow size, turning frequency, and combining windrows. These operations need to be controlled to ensure proper temperature, moisture, and oxygen level.

Public safety concerns are an important issue. The compost product should be free from any pathogens or harmful substances. Proper laboratory analysis will validate the quality of the end product.

Recommendation #6. Elevated temperatures (i.e., 122 to 170°F) are required to sustain the microbial populations responsible for decomposing the compost mass. In addition, high temperatures are required to destroy any plant and animal pathogens which may be present. The Air Force should use long-stem temperature probes to monitor and manage the temperatures of the compost.

Recommendation #7. Professional chemical analysis of the composting materials during the compost process and of the finished compost is necessary to ensure a clean, safe, and fully decomposed final product. The Air Force should contract with a local laboratory or university for seasonal sampling of the compost to determine C/N ratio, presence and levels of pathogens, and heavy metals content.

Evaluation of Analysis Process

The research methodology is not grounded in scientific procedures but is based on common decision making criteria. In choosing a composting program, it is imperative to understand the composting process from both the technical and practical points of view. An evaluation of the research procedure is necessary to validate and verify recommendations.

The analysis of both the technical and practical aspects of the composting process resulted in specific recommendations for the Air Force by providing answers to the stated objectives.

The literature review was the most extensive aspect of the research. There could not be adequate recommendations for the Air Force without the consultation of present guidance. State manuals and textbooks quickly narrowed down the field of alternatives for developing base level composting programs.

Site visits provided a good perspective of the "big picture". The visits provided insights on the total composting operation and revealed the driving factors behind developing a strong compcsting program: landfill tipping fees, end markets, and type and volume of waste.

Interviews with knowledgeable compost managers were limited. There are more DoD managers that could have provided additional, useful information but were not contacted. Future research needs to include a large survey of DoD managers.

Bottom Line

The research did produce specific guidelines for the Air Force for the development of composting programs at every installation. The Air Force should compost yard waste since this technique has proven to be successful in diverting the flow of waste from landfills for many communities and companies. Yard waste composting is feasible for the Air Force and will prove to be the strength behind the solid waste reduction goals already established for Air Force bases.

Many states have comprehensive guidance manuals that are an excellent source of practical knowledge. Each base should procure one of these guides for additional information. Yard waste composting is well understood and the guidance already in print is applicable for implementation by the Air Force.

XI. Conclusions and Further Insights

Significant Findings

The American people should become better informed on how their personal activities are affecting the global environment. Uncontrolled pollution is a continuing dilemma for individuals and environmental policy makers in both the public and private sectors. While laws and regulations are important, they alone are not the answer to pollution. This problem may in many cases be addressed on an individual basis. Each of us must do our part. Giving "lip service" to environmental problems will not solve them. Every one of us must take the responsibility to clean up the environment.

However, clean-up is not enough. We must stop polluting. We must change our attitudes. We cannot continue to treat the world as a dumping ground for any unwanted material. The pollution picture is bleak, but not hopeless. Many pollution prevention programs are active and many more are being developed to address pollution prevention opportunities. We are making an effort on a national scale. We all must do our part instead of relying on the "next guy" to do it.

Composting as a waste management alternative to land disposal is finally receiving the attention it deserves. Composting is not new. It has been practiced by farmers, nurseries, and backyard gardeners for centuries. Now,

when we produce more garbage than we have landfill space, we must adapt compost technology to the entire waste stream.

Composting is a growing solid waste management initiative as proven by the number of state reduction goals and yard waste landfill bans. The Air Force is at a time and place where composting is a feasible, viable option for reducing the solid waste produced on installations. Each base should initiate a composting program and should include solid waste reduction as part of pollution prevention education of all Air Force base personnel.

Installations need to combine the knowledge of what works for other bases and communities to build a network of successful composting initiatives. The best way to learn how to build a strong composting program is to visit sites that are already composting and gather composting information from as many people as possible. Nothing can replace the knowledge gained by firsthand experience.

The recommendations provided by this research are applicable to all Air Force bases and may be used to facilitate the implementation of base-wide composting programs. This thesis is not meant to be inclusive of all information required to begin a composting program, but provides insight into the decision making process and the criteria that are important to the success of composting yard waste.

Three Key Decision Factors. Figure 24 displays the major drivers for building a composting program. These three factors will govern the entire design of the composting process. Even though there are many choices and desicions to make in starting a composting program, all decisions hinge on the following factors.

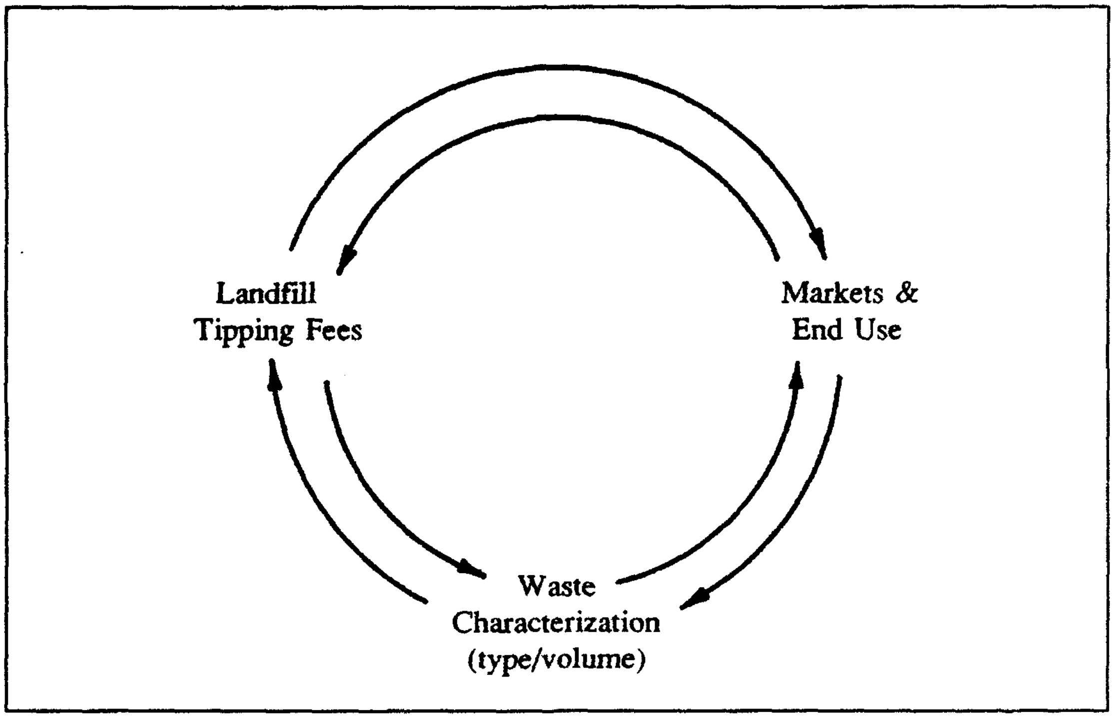


Figure 24. Three Key Decision Factors for a Successful Compost Program

Landfill tipping fees are set by the local landfill and reflect the value of land and the cost of future landfill expansion. Charges range from just a few dollars to over $125 in various parts of the country (49). This variance shows the diversity of costs and the location of some existing compost operations. The

majority of the compost operations are located in areas were the tipping fees are high. This is true because tipping fees determine the cost avoidance potential for composting and the amount that can be charged for incoming compostable material (if applicable).

The market and end use will define the quality of the compost. These factors determine the need for additional equipment such as windrow turners, grinders, and screeners. By understanding the market, the compost operation can be designed to efficiently meet the objectives but not create unnecessary expenditures.

Character, type, and volume of material in the compost waste stream are factors used to choose the level of technology. They are also used to design the size of the compost operation and the site requirements.

Figure 24 presents a graphical representation of the interrelationships between the three key decision factors affecting composting. It is important to realize that these factors are not independent. Each is constrained by the other two and all three need to be considered simultaneously during the planning and design process to ensure a sound composting program.

Impacts of the Research

The impact of this research is twofold: 1) personal achievement and development of the authors, and 2) a contribution of usable knowledge that is beneficial to the Air Force.

Personal Development. The knowledge and insight gained by completing the research will be beneficial in all future areas of environmental and personal management. During the research process, the issues of validity and reliability were made unmistakably clear. It is imperative that all sources are well documented and that all assumptions, recommendations, and conclusions are based on fact, not on opinion or speculation. This not only pertains to this research process, but to all knowledge that is used to make decisions--it must be well documented and reliable.

Contribution to the Air Force. Composting is now mandated for all Air Force bases and this research is a tool to help local solid waste managers meet the Air Force's high expectations and specific waste reduction goals.

The Air Force wants to be a leader in solid waste management and this document provides the information needed to establish strong, local composting programs rooted in an effective design and planning process. With the aid of this document, the Air Force is well on its way to establishing strategic solid waste management guidelines which integrate composting as an important aspect in achieving the specific goals set forth in AFR 19-4.

Future Research Areas

The focus of this research has been on the composting process from an operations point of view with additional guidance on program management. The knowledge of the composting process is prerequisite to the study of

additional composting issues. Future research should address two additional areas: 1) macro-management of composting with respect to the total solid waste agenda, and 2) computerized decision making models for use in establishing composting programs.

Macro-Management of Composting. Composting is one area in the strategic outlook of reducing solid waste disposal in landfills. It is important to comprehend how composting fits into the "big picture". Often, it is easy to lose perspective by concentrating on minor issues while misunderstanding the best approach for the benefit of the entire program.

Interviews with solid waste management decision makers would reveal the information necessary to create a clear purpose for the Air Force's solid waste management program. It would be based on current trends and insights. The interviews should provide knowledge of the overall solid waste process and how each program (recycling, composting, incineration, disposal) is managed in an effective manner.

Computerized Decision Making Model. Computerized information systems are prevalent. Future development of automated decision support systems (DSS's) would be useful for composting managers and decision makers. Beyond tracking and recordkeeping, a computer model could be used in the planning process to guide the choice of composting alternatives. Expert systems are another approach to help the decision making process. Expert systems are

computer based knowledge systems which operate on a "rule of thumb" approach where advice is given based on certain inputs and criteria.

Further Study of Composting Options. Yard waste is a natural material to compost and is popular among communities trying to reduce landfill disposal. It is easily separated from the waste stream and can be composted for use as a soil amendment or mulch. In these days of environmental stewardship, composting is the politically correct, "right thing to do" and attention is centered on additional ways to reduce solid waste disposal. If it has not been mandated in a state, it soon will be (see Appendix D).

Yard waste is not the only organic material that can be composted to minimize landfill disposal. Food and paper wastes, as well as mixed municipal solid waste, can be composted as proven by many pilot and test programs in communities around the country. Extensive research has already been completed in the field of sewage sludge composting.

The options of mixing food, paper, or mixed waste with yard waste or composting them separately need to be studied. The best approach for composting these additional materials needs to be investigated to better understand the viable options beyond composting only yard waste.

Case studies of existing communities that are composting various organic materials would be a good way to critique the effectiveness of composting these materials. It would also give insight into the correct and incorrect methods that

should be applied to the composting process. Recommendations are needed to help communities decide when to cross over from composting only yard waste to adding some other materials.

Case studies involving co-composting sewage sludge with other organic materials would be beneficial. Since both are plentiful, future research could provide guidance on the compatibility of these materials. Case studies also provide a unique insight into best management practices that are often not mentioned in the literature.

Further Study of Solid Waste Management. The management of solid waste encompasses both composting and recycling as well as landfill disposal and incineration. Research needs to be completed to assess the current Air Force solid waste management program. With the continuous changes in minimizing landfill disposal, a comprehensive, strategic plan needs to be developed for use by the Air Force.

From an Air Force perspective, there also needs to be a centralized solid waste management information system with the capability of tracking and recording all solid waste streams and associated management transactions. This system could be used to develop future strategy and policy guidance from the Air Force as well as provide real information on the effectiveness of various waste management initiatives.

Solid waste management activities at base level have traditionally been centered on recycling. Currently, Morale, Welfare, and Recreation operates most of the recycling programs while the Civil Engineering Squadron will be tasked with operating the composting programs. There is no centralized, unified management of the solid waste management program. This needs to change to provide a coherent and responsive program at base level. By achieving a unified approach to municipal solid waste management, the Air Force will continue to be a leader in the field of waste disposal.

Appendix A: Steps for Starting a Composting Program

Starting a successful composting program requires proper planning. The various tasks associated with each project phase are listed in the following outline.

I. Feasibility Study and Conceptual Design

1. Identify quantities and composition of wastes for municipal composting

2. Identify and investigate end uses of the final product

3. Evaluate existing collection system, identify required modifications

4. Identify and evaluate potential sites

5. Evaluate potential environmental impacts

6. Identify institutional requirements and permit requirements

7. Assess public support
   - home composting and recycling grass clippings
   - participation in municipal collection
   - as users of final product

8. Perform conceptual design
   - site requirements
   - structural requirements
   - general design and site layout
   - equipment requirements
   - operating procedures
   - personnel requirements

9. Perform preliminary economic analysis
   - capital costs
   - operating and maintenance costs
   - potential revenues
   - avoided costs

10. Identify financing options

11. Formulate conclusions and recommendations
    - select site
    - determine owner/operator
    - determine financing methods and obtain funds

II. Design and Engineering

1. Initiate necessary permits and approval procedures

2. Establish collection system requirements and procedures

3. Prepare detailed design of facility
   - surface and drainage
   - receiving area layout
   - windrow area layout
   - storage/curing area
   - utility hook-ups, if needed
   - building/structures
   - access roads
   - fencing
   - irrigation system, if needed

4. Prepare equipment specifications

5. Establish uses for end product and obtain commitments

6. Establish personnel requirements

7. Prepare operating plan

8. Develop public education program
    - home composting and recycling lawn clippings
    - participation in municipal collection system
    - as users of final product

9. Perform detailed economic analysis

III. Construction and Operation

1. Procure equipment
2. Implement public education program
3. Make site improvements
4. Hire personnel
5. Begin operations
6. Maintain records
7. Evaluate the project regularly
8. Refine operational procedures

(27:51)

Appendix B: Low-Level Technology Composting Implementation Guide

Many of the components of the process described below are common to all composting operations. Many communities begin composting operations with only leaves in the first year, and the following methodology focuses on leaf composting alone. Ultimately, all yard wastes can be successfully composted, but it is sometimes advisable to begin composting with leaves alone, adding new materials as experience is gained and the needs of the community are better understood. The inclusion of grass clippings and other yard wastes in the composting system is discussed in sections 10 thru 12. Also, including grass clippings in windrows will shorten the composting times given below.

The simplest way to achieve the ideal temperature range for composting is to build windrows large enough to conserve sufficient heat, but not so large as to overheat. On the other hand, adequate oxygen flow will be achieved if the windrows are small. Unfortunately no single windrow size completely reconciles these conflicting goals. The desired conditions can be approached by starting with moderately sized windrows (6 feet high by 12-14 feet wide), then combining two windrows after the first burst of microbial activity (which lasts approximately one month). Colder climates may require somewhat larger windrows to insulate the heat within the windrow.

It is possible with this approach to produce a thoroughly decomposed (finished) leaf compost in 16-18 months. If windrows are initially formed in autumn, the compost will be ready for use in spring (18 months later), which is the time of peak demand for the product. Slight odors may be produced early in the composting cycle, but these are usually not detectable more than a few yards away from the windrows. After 10-11 months, large curing piles can be formed around the perimeter of the site, freeing the original area to accept new materials. Costs are still quite low, as only three operations with a front-end loader are required after initial windrow formation (one combining, one turning, and one curing pile formation). Despite the fact that more space is required for the actual composting (roughly 1 acre per 3000 to 4000 cubic yards of leaves) compared to the basic windrow method, less total area is needed overall because of the reduced buffer requirements.

The individual steps are discussed in more detail below.

1. Site Preparation

Prior to each collection season, the site must be readied to allow necessary truck access and front-end loader operation. The one part of the operation which has little scheduling flexibility is delivery of the collected

wastes. Once leaves are collected, they must be promptly formed into windrows (sections 2-4 below). It is critical, therefore, to prevent operational bottlenecks, such as an area becoming so muddy that trucks get stuck trying to drop off their loads.

The yearly site preparation should include regrading and road maintenance. Also, all refuse and debris from the previous year's operation should be removed. Normally this step will require at most a few days work. It can be scheduled any time after the active site has been cleared of the materials from the previous year (by formation of curing piles), but before the new collection season begins.

2. Receiving and Sorting

It is recommended that trucks dump their loads of leaves in a staging area, rather than trying to form windrows directly. Although a staging area involves additional labor, its use is justified for several reasons.

Controlling the feedstock to a compost operation can prevent severe contamination of the end product. In a staging area, unwanted materials such as plastic, metal, glass, large stones, wire, and rope should be removed from incoming loads by use of a front-end loader (or other mechanical means) and hand sorting, since such materials damage composting equipment and degrade the quality of the end product. Good collection system management and close monitoring of incoming loads are essential to minimize levels of such contaminants.

Wood and brush should also be removed from incoming loads. Wood in the windrows should be avoided, since wood decomposes very slowly and the presence of undecomposed wood is unacceptable for most compost uses. Large pieces of wood can be cut for firewood or chipped, and chipped wood and brush can be used to form all-weather roads at the compost site or to create a base for windrows.

Leaves are normally collected in several ways and delivered in a variety of trucks, including garbage compactors, roll-offs, and vacuums. Use of various collection equipment results in incoming loads that are not uniformly compacted. If windrows are formed directly from collection vehicles, compacted leaves may not receive adequate oxygen. This problem can be minimized by breaking up and fluffing incoming materials in a staging area. Wetting is also virtually impossible in directly formed windrows since most of the water simply runs off the outside. Use of a staging area also leads to a more uniform windrow size and shape, giving both a better appearance and more efficient composting. Keeping trucks on the firmer surfaces rather than backing into windrows decreases the chance of trucks getting stuck during wet

weather. Even in good weather, the staging area can speed delivery process. It may be feasible to move the staging area periodically (weekly for example), to minimize the distance to the active windrow-forming area.

Windrow formation must take place soon after leaves are received. If freshly dumped leaves are allowed to sit for more than a day or so in the staging area, odor problems may develop. Some minimal supervision may be required to prevent dumping in undesired locations. Also, a record of the amount of leaves delivered should be kept. A daily tabulation of the number of loads for each individual truck of known capacity may be the best accounting method.

At most leaf composting facilities, the leaves are delivered in bulk. However, some sites may find it necessary to accept at least a portion of their capacity in plastic bags. These bags can be handled successfully but pose considerable extra problems. The bags should be dumped in a separate portion of the staging area. In a very labor intensive process, they must then be slit open and emptied. (Some operations use community service labor). Any trash must be separated and disposed of along with the bags. If mixed trash is a persistent problem, an educational campaign is recommended and/or leaves might be accepted in transparent bags only. Another difficulty with collection of bagged leaves is the odor released from some of the bags upon opening. One alternative is to open and dump the bags directly into the hopper of the collection vehicle during the collection process. While this practice slows the collection crews, it prevents double handling of the bags and provides for greater control over feedstock quality.

Programs which use a drop-off site for residents should require participants to unbag their own wastes in order to take plastic bags back home for reuse. Drop-off sites should have some method for monitoring incoming loads to avoid contamination of windrows with other wastes.

3. Wetting

Wetting of the leaves is required during much of the collection season. Adequate wetting can only be achieved prior to or during windrow formation or when windrows have been opened up for turning or other purposes. Most of the water applied to the outside of a windrow is simply shed by the leaves. The water should be sprayed in excess on the leaves with a hose as the loader breaks the masses apart in the staging area, and/or as they are placed in the windrows.

As a rough approximation, 20 gallons of water will be required on average per cubic yard of leaves collected. On a more informal level, the rule of thumb is that it should be possible to squeeze a few drops of water from a fistful of the leaves.

The need to add water can be reduced or eliminated by forming windrows with flat or slightly concaved tops, in order to catch precipitation and induce percolation of moisture down through the windrow.

4. Forming Windrows

Once the leaves have been dropped in the staging area, the front-end loader can be used to break apart and spread the compacted materials to facilitate wetting. The front-end loader can then be used to place the uncompacted leaves in windrows.

The windrows initially can be 6-8 feet high by 12-14 feet wide. Any convenient length can be used. Windrows that will be left over winter should be 10-12 feet high by 30-40 feet wide to prevent freezing in cold climates. Two windrows can be formed side by side, with only 1-2 feet between, to conserve space. Sufficient aisle space between pairs of windrows (typically 12-16 feet) should normally be allowed for loader operation. Although in some cases it may be possible to have fewer aisles if space is limited, this makes turning operations awkward.

Neatly formed windrows with well maintained aisles give a professional appearance to the facility, while messy windrows give the impression of a "leaf dump". Care should be taken that equipment, especially the loader, does not ride up on the windrows, compacting them. Loosely piled leaves are required in order to maintain adequate air penetration into the windrows.

5. Monitoring Decomposition

Compost windrows should be monitored closely to ensure that decomposition proceeds properly and does not create a nuisance. Monitoring should consist of daily temperature readings at several points in each windrow and twice-per-week inspections for moisture content, physical appearance, and internal windrow odors.

Daily temperature readings are especially good indicators of the development of problems before they become major. Sharp drops in temperature, for example, may indicate decreasing moisture content or the onset of anaerobic conditions. Failure of temperatures to rise to 120-160°F shortly after windrow construction may indicate a poor carbon/nitrogen ratio or improper moisture content. In both these cases physical inspection of the windrows would probably reveal the source of the problem. An anaerobic pocket, for instance, might be tightly packed, emit unpleasant odors, be very

wet, and possibly have a green or shiny black appearance. Prompt aeration would prevent the problem from becoming a major nuisance.

6. Combining Windrows

After approximately one month, much of the initial oxygen demand of the leaves has been exerted and the windrows have been reduced to about half their original size through decomposition and self-compaction. At this point, two windrows can be combined to form a single one about the same size as each of the initial windrows. Combining the windrows will help conserve heat during colder weather. Portions of the center of the new, combined windrow may go anaerobic temporarily, but significant odors and acidification are not expected because much of the readily degradable material has already been consumed by the microorganisms.

Combining should be done by moving and turning both windrows, not by placing one on top of the other. The maximum degree of mixing and fluffing is desired. To conserve space, combining may begin before leaf collection has been completed. In this way some of space freed by combining windrows (formed with leaves collected early in the season), can be used for new windrows made with leaves collected late in the season.

7. Turning Windrows

As early as is practical in the spring (March or April), each windrow should be turned. Turning mixes the material, redistributes the moisture in the windrow, reoxygenates the interior, and exposes the formerly cool edges to the hotter internal temperatures. The result is an increased rate of decomposition and improved destruction of any pathogens and weed seeds.

As with the prior combining operation, maximum mixing and fluffing is desired during turning. At this time additional water may be added if the material is too dry; however, every effort should be made to provide sufficient water initially. Additional turnings throughout the summer would further enhance composting rate and product quality, but these turnings are optional.

8. Curing

Using the composting method described here, much of the material will not be completely stabilized by the end of the summer, yet the composting area must be cleared to allow for site preparation for the next year's leaves. This

does not represent a problem since the material is now moderately well decomposed, has little oxygen demand, and is unlikely to produce odors.

At this time, therefore, the material can be moved and formed into a large curing pile around the perimeter of the site. The curing pile may be made as large as desired to conserve space, but should not be compacted when formed. Moving the material also provides additional turning and mixing, and exposes a relatively small surface area to drying and freezing conditions. Additional weed and pathogen destruction is achieved at the temperatures reached within the large, well-insulated curing pile. This material is expected to be well stabilized by the following spring but may be left in place longer if convenient.

9. Shredding

Once composting is completed (post-curing), shredding is a final optional step to improve the physical quality and appearance of the finished compost, making it more acceptable for many uses. Shredding breaks up clumps and separates out rejects consisting of any uncomposted leaves, branches, rocks, plastic, and other extraneous materials. Organic "rejects" may be composted for an additional period, then reshredded to minimize the amount requiring disposal. *Shredding is fairly labor intensive. Leaf compost can only be processed at* about half the rated capacity of the equipment. Shredding will proceed more rapidly if the compost is not too wet. Moist material to be shredded can be spread out to dry for a day or two beforehand.

The major advantage of using a shredder is that it yields a more uniform and debris-free final product. It can also be used to mix finished compost with soil. Disadvantages include the labor and equipment requirements, the need to dispose of rejects, and of course the capital cost of the specialized machine. One way to reduce costs is to share a single unit among several sites or communities. Sharing is possible since the specialized equipment is only needed for a month or two per year, and scheduling can be flexible.

10. Grass Clippings

Grass clippings represent a significant seasonal waste management problem. In some communities they may account for nearly one-half of the total municipal refuse load during peak grass-growing periods.

The best alternative for grass clippings is not to collect them at all. Turf specialists recommend mowing frequently enough so that the short clippings filter through the growing grass and return their nutrients to the soil. Contrary

to popular belief, this practice does not contribute to thatch. If the clippings are collected they can be incorporated in moderate amounts in back yard composting piles and used as a garden mulch.

Municipal composting of both leaves and grass clippings is not as widely practiced as composting leaves alone but can, with controlled conditions, provide excellent results.

Since they are typically still green when collected, grass clippings are relatively high in nitrogen, moisture content, and readily degradable organics compared to the leaves collected in autumn. For these reasons they decompose more rapidly, have a higher oxygen demand, and quickly go anaerobic. They are often highly odorous by the time they are delivered to a composting site. Therefore it is especially important to properly implement (and strictly enforce) odor control measures. Additional precautions such as enlarging the buffer zone may also be necessary.

It is desirable that grass clippings be incorporated into a leaf windrow before the end of the day of delivery. A 50:50 ratio of leaves to grass clippings provides an optimum carbon to nitrogen ratio, although starting out with a higher ratio of leaves to grass will lessen odor problems until experience is gained. Good mixing is essential and can be done with a front-end loader by working together 20-30 bucketfuls of material at a time, then forming a windrow with the mixture.

Once the material has been mixed in this way, no further odor problem is expected. The partially composted leaves act as a bulking agent to improve penetration of oxygen to the grass clippings. The grass in turn speeds the decomposition of the leaves by providing needed nitrogen. The end result is a higher quality compost product which is ready in a shorter period of time. However, these benefits must be balanced against the increased potential for odor problems. When green weeds are also incorporated into the windrow, they can be considered as identical to grass clippings for the purposes of composting. Large quantities of diseased plant wastes should be excluded from compost windrows.

A common concern about composting grass clippings is the potential presence of lawn chemicals in the finished compost. While there is some debate on this topic, most commonly used lawn pesticides degrade in 6-8 weeks and, therefore, compost made from yard wastes will generally be free of significant quantities of lawn chemicals. Further, concerns about the toxicity of materials used in agriculture usually center on the uptake of heavy metals by plants grown in treated soil. Finished compost made from yard wastes typically contains extremely low levels of heavy metals.

11. Woody Materials

Wood tends to decompose very slowly, making composting of woody materials impractical in most cases. Thus woody materials should not be intentionally incorporated in leaf composting windrows. Small amounts of incidentally included branches and twigs pose little problem.

Tree trunks and large branches can usually be easily given away or even sold as firewood, if cut to reasonable lengths. For smaller diameter woody materials, chipping produces a useful mulch. Many communities have had great success using wood chips as mulch or bedding for municipal landscaping, park pathways, and school playgrounds. Residents also appreciate free wood chips for use in their own yards.

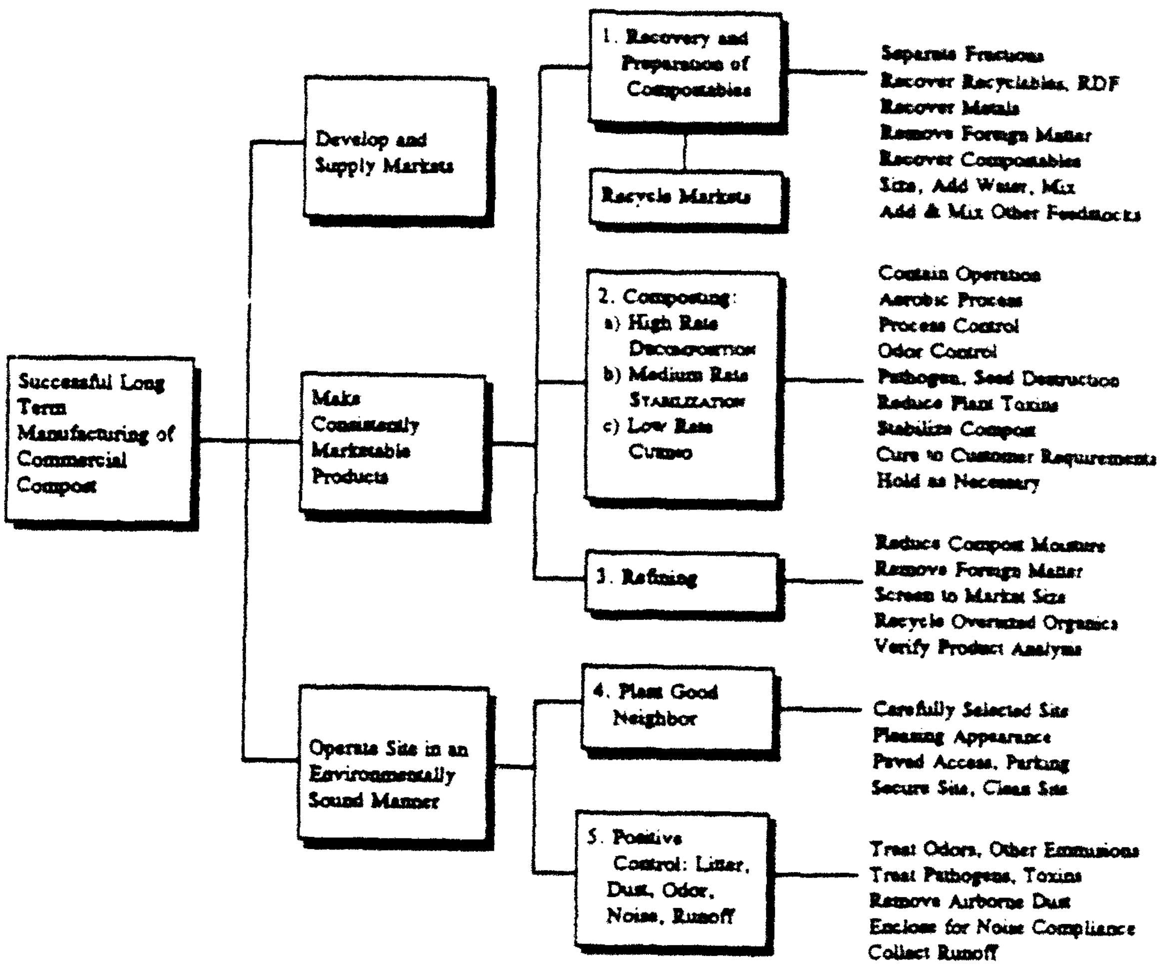
Wood chips are valuable at the compost site to form roads and all-weather work surfaces. Small quantities of wood chips that may get mixed in with the compost will not adversely effect the quality of the final product.

12. Pine Needles

Pine needles can be successfully composted if they are mixed with grass and leaves. However, since pine needles decompose very slowly, the formation of windrows containing almost exclusively pine needles should be avoided. Christmas trees should be treated as woody materials.

(27:20-31)

Appendix C: Compost Facility Planning Guide for Municipal Solid Waste Mixed Organics Composting



(4)

Appendix D: State Legislation and Landfill Bans

Landscape and Irrigation published an article in the June 1992 issue which listed each state and the status of its' recycling legislation. Lawn-Boy conducted a telephone survey in 1992 based on calls to Department of Natural Resources contacts in the 50 states and Washington DC (23:16).

Alabama: Effective in 1991, Alabama state-funded agencies, such as schools, parks and government office complexes, were required to recycle their yard waste. The state's waste reduction goal is 25 percent by 1995, allowing up to 10 percent to be met with composting and/or mulching. Citizen and county cooperation is extremely high. Of the 67 counties, more than half have indicated that they will be composting waste.

Alaska: No legislation in place or on the docket for 1992.

Arizona: No legislation in place or on the docket for 1992. The state does not have a waste reduction goal. However, yard waste (primarily from palm trees) comprises 47 percent of all waste. Phoenix has a drop-off site for yard waste.

Arkansas: Effective July 1993, yard waste disposal at landfills will be banned. Municipalities are currently setting up large-scale composting facilities and the state is developing a consumer education program.

California: Counties must decrease solid waste by 25 percent by 1995 and 50 percent by 2000. There is no progression towards legislating a yard waste ban to landfills.

Colorado: No legislation in place or on the docket for 1992. Successful community recycling program includes leaf composting and leaving clippings on the lawn. Boulder's leaf composting program is currently the most successful municipal recycling program in the state.

Connecticut: In January 1991, leaves were banned from landfills. Most leaves are composted at municipal sites. In 1990, the state reversed an unsuccessful yard waste ban to landfills. At that time, the state issued a list of eight materials, including leaves, that must be recycled in an effort to reduce solid waste by 25 percent.

Delaware: The state is aiming to recycle 30 percent by 1994, with a 20 percent composting target. There is no progression towards legislation banning yard waste disposal.

Washington D.C.: In October 1989, yard waste was banned from landfills. There is a 35 percent waste reduction goal by 1992 and 45 percent waste reduction goal by 1994. The ban has been effective with relatively few implementation problems. The only obstacle has been educating citizens to separate their garbage. The Department of Public Works continues to pick up yard waste, only now they transport it to a composting site.

Florida: On January 1, 1992, yard waste was banned from all lined landfills. However, yard waste is still accepted in unlined landfills. The state has a 30 percent waste reduction goal by 1994. Counties are required to set up alternative methods of yard waste disposal or provide hauling service to unlined landfills.

Georgia: The state has a 25 percent waste reduction goal between 1992 and 1996. The state gave landfill operators the right to ban and/or restrict yard waste. Many landfills have done this. Of those refusing yard waste, some continue to provide curbside pickup, but they take the yard waste to a separate yard waste facility. Others require citizens to compost yard waste themselves. A number of inert landfills have opened specifically for yard waste.

Hawaii: The state has a 25 percent waste reduction goal by 1995 and 50 percent by 2000. Statewide legislation banning yard waste disposal in landfills is considered too complex. The state is trying to pass a resolution that would allow counties to develop plans for banning green waste from landfills, with plans due by January 1993.

Idaho: No legislation is in place or on the docket for 1992.

Illinois: On July 1, 1990, yard waste was banned from landfills. Counties with populations of more than 100,000 have a 15 percent waste reduction goal by 1994 and a 25 percent goal by 1996. Counties with populations less than 100,000 have a 15 per cent waste reduction goal by 1998 and 25 percent by 2000. The ban has been extremely effective in eliminating yard waste from landfills. However, there have been problems developing composting facilities because of many restrictions.

Indiana: The state has a 35 percent goal for reducing landfilled and incinerated waste by January 1, 1996 and 50 percent by January 1, 2001. A state bill banning yard waste from landfills will be introduced in the legislature in 1992. If the bill fails, districts will ban yard waste from their local landfills to meet the waste reduction goals.

Iowa: In January 1991, yard waste was banned from landfills. The state has a 25 percent waste reduction goal by 1994 and 50 percent by 2000. Municipalities are responsible for determining recycling methods. Those communities that provide garbage and/or yard waste pickup are required to continue pickup service. However, citizens are required to separate yard waste. The ban has been extremely effective, with few obstacles. This is attributed to the continuation of curbside pickup.

Kansas: No legislation in place or on the docket for 1992. The city of Parsons already has restricted yard waste from its landfills, composting it instead. Some counties are charging a tipping fee for yard waste at landfills.

Kentucky: The state has a 25 percent waste reduction goal by 1997. There is no statewide legislation banning yard waste disposal at landfills. However, municipalities and counties have the authority to ban yard waste from landfills. Some have taken such action.

Louisiana: The state has a 25 percent waste reduction goal by Dec. 31, 1992. There is no legislation on the docket in 1992 for banning yard waste disposal.

Maine: The state has a 50 percent waste reduction goal by 1994. A yard waste ban was introduced in the legislature in 1991. It was rejected. Although the legislators are concerned with landfilling yard waste, they don't want to impose state laws on what they consider to be a local issue. Many municipalities are considering banning yard waste disposal in landfills.

Maryland: The state has a 15 to 20 percent waste reduction goal by 1994. Responsibility is at the county level. Some counties promote backyard composting and mulching while others collect yard waste, compost it and sell it. Some counties are considering banning yard waste from landfills.

Massachusetts: On December 31, 1991, leaves were banned from landfills. On December 31, 1992, yard waste will be banned from landfills. The state aims to recycle 46 percent of generated waste and reduce total waste by 10 percent by 2000. With numerous recycling programs across the state,

citizens are fairly knowledgeable of alternative methods of yard waste disposal. Of 351 towns in Massachusetts, 105 already have mandatory separation of garbage, 268 have recycling programs in place and 128 have composting facilities.

Michigan: On March 31, 1993, yard waste from state municipal lands will be banned from landfills and incineration. On March 31, 1995, there will be a statewide ban of all yard waste to landfills. After March 31, 1995, incineration of yard waste will only be allowed in communities with populations of less than 7,500. The state aims to reduce waste by 50 percent by 2005. It is the responsibility of the local municipalities to meet the state regulations. Many landfills already refuse yard waste.

Minnesota: In January 1990, seven counties banned yard waste to landfills. In January 1992, a statewide yard waste ban went into effect. The state's goal is to reduce waste by 25 percent by December 31, 1993. The ban has been extremely effective. Most areas offer yard waste pick up and drop-off sites.

Mississippi: The state has a 25 percent waste reduction goal by 1996. There is no progression towards legislating a yard waste ban to landfills. However, if the waste reduction goal is not met in 1996, additional legislation will likely pass.

Missouri: In January 1992, yard waste was banned from landfills. The state's goal is to recycle 40 percent by 1998. The state has developed 37 sites for community composting.

Montana: The state's waste reduction goal is 25 percent by 1996. The state is setting up a solid waste plan that counties will follow.

Nebraska: The state's waste reduction goal is 25 percent by 1994, 40 percent by 1997 and 50 percent by 2000. There is no progression towards legislating a yard waste ban to landfills.

Nevada: The waste reduction goal is 25 percent by 1994. The state does not have any responsibilities to specific yard waste recycling.

New Hampshire: The waste reduction goal is 40 percent by 2000. Proposed bills banning leaves and other yard waste to landfills and incinerators will be introduced at the next legislative session. Municipalities feel it will be

too costly to find alternative methods of disposal, so there are obstacles to banning yard waste disposal in landfills.

New Jersey: In August 1989, leaves were banned from landfills. The state's goal is to recycle 60 percent by 1995. There is progression towards legislating a yard waste ban, however, there is nothing on the docket for 1992.

New Mexico: The state's goal is to divert 25 percent of all waste by July 1995 and 50 percent by July 1, 2000. There is no progression towards legislating a yard waste ban.

New York: The state's recycling goal is 40 percent and its waste reduction goal is 10 percent by 1997. Currently, there are 150 centralized yard waste composting facilities in New York that offer pick up and/or drop off service. Legislation banning yard waste disposal has been introduced in the past and failed.

North Carolina: On January 1, 1993, yard waste will be banned from landfills. There are 42 centralized yard waste recycling facilities.

North Dakota: The waste reduction goal is 10 percent by 1995, 25 percent by 1997 and 40 percent by 2000. The state is divided into eight segments. Each monitors its own waste and has the right to ban yard waste from landfills. Fargo has already banned yard waste disposal. Many cities have municipal facilities for yard waste composting.

Ohio: On December 1, 1993, leaves, grass and brush will be banned from landfills. The state's waste reduction goal is 25 percent. The state's 48 separate solid waste districts were each required to submit a recycling plan to the Ohio EPA. Some municipalities have already banned yard waste from landfills. Others are discouraging bagging yard waste. Some municipalities are encouraging haulers to charge extra for yard waste removal.

Oklahoma: The state's waste management plan with five-, 10- and 20-year waste reduction and recycling goals will be completed July 1, 1993. There is no legislation restricting yard waste disposal in place or on the docket for 1992.

Oregon: Each county has been assigned a waste reduction goal, which is based on population, to be met by 1995. The statewide waste reduction goal is

50 percent by 2000. At almost 25 percent, Oregon has one of the highest recycling rates in the country. With the successful volunteer programs, there is no progression towards legislating a yard waste ban.

Pennsylvania: In September 1990, leaves were banned from landfills and incinerators. The waste reduction goal is 25 percent by 1997. In many areas, leaves continue to be picked up and then composted or spread over farm fields. Legislation was introduced in 1990 to include other yard waste in the leaf ban, but it did not pass.

Rhode Island: In January 1993, leaves and commercial yard waste will be banned from landfills. In January 1994, a statewide yard waste ban will take effect. Businesses will be required to transport their yard waste to a centralized composting facility.

South Carolina: In November 1992, yard waste will be banned statewide from municipal landfills. However, inert landfills designed especially for green waste will accept yard waste. The state's waste recycling goal is 30 percent with a maximum of 15 percent derived from yard waste recycling over the next seven years.

South Dakota: The waste reduction goal is 25 percent by 1995, 35 percent by 2000 and 50 percent by 2005. Currently, one segment of the state bans yard waste from landfills. South Dakota does not want to pass a statewide ban, but would rather continue to allow each county to determine its own recycling methods.

Tennessee: The state's waste reduction goal is 25 percent at municipal solid waste disposal facilities and incinerators. By December 31, 1995, that goal also will apply to residents. There are significant recycling programs in the state. Nashville and Memphis have yard waste composting facilities run by the city. Both cities have yard waste collection and drop-off recycling sites for citizens.

Texas: The state's waste reduction goal is 40 percent by 1994, with 15 percent of that goal achieved by composting. There is no progression towards legislating a yard waste ban to landfills. However, if the 40 percent gaol is not met and voluntary programs are not successful, a statewide yard waste ban from landfills may be legislated.

Utah: Legislation that calls for phasing out yard waste from landfills serving metropolitan areas will be introduced this year.

Vermont: The state's waste reduction goal is 40 percent by 2000. A statewide yard waste ban has been discussed, however, it is not on the docket for 1992.

Virginia: The state's recycling goals are 15 percent by 1993 and 25 percent by 1995. There is no progression toward legislating a statewide yard waste ban to landfills. However, a bill was passed enabling municipalities to ban yard waste from landfills. Virginia Beach has done this.

Washington: The waste reduction goal is 50 percent between 1992 and 1994. Statewide legislation banning yard waste from landfills has been discussed and could be introduced later in 1992 or in 1993.

West Virginia: In January 1993, yard waste will be banned from landfills. The state's waste reduction goals are 20 percent by 1995 and 30 percent by 2000. Counties are responsible for preparing citizens for the ban and educating them on alternative methods of disposal. Many counties will be setting up centralized composting facilities while others will encourage citizens to recycle their own yard waste.

Wisconsin: On January 1, 1993, yard waste will be banned statewide from landfills. Dane and Chippewa counties have already banned yard waste from landfills, as have many municipalities.

Wyoming: There is no legislation in place or on the docket for 1992 restricting yard waste from landfills. Many communities are developing centralized composting programs.

Appendix E: Troubleshooting Guide

This Table lists possible causes and solutions for problems frequently occurring in composting.

Problem	Causes	Solution
Anaerobic odor	Excess moisture	Turn windrow
	Windrow too large	Make windrow smaller
	Temperature greater than 140 F	Turn windrow
	Leaf compaction	Turn or reduce windrow size
	Surface ponding	Eliminate ponding
		Apply odor masking agent (cures symptom, not problem)
Low windrow temperature	Windrow too small	Combine windrows
	Insufficient moisture	Add water while turning windrow
	Poor aeration	Turn windrow
High windrow temperature	Windrow too large	Reduce windrow size
	Leaf compaction	Turn windrow
Surface ponding	Depression or ruts	Fill depression and/or regrade
	Inadequate slope	Grade site to recommended slope design
Vectors Rats	Presence of garbage (food, etc.)	Remove garbage, or use rat bait
Mosquitoes	Stagnant water	Eliminate ponding

Problems	Causes	Solutions
Pollution of surface waters	Leachate discharge	Treat leachate before it leaves site by passing it through soil, sand, or grass filter area.
		Avoid surface runoff
Fires/spontaneous combustion	Excessive temperature	Make windrow smaller
	Inadequate moisture	Add water
	Stray sparks, cigarettes, etc.	Keep potential fire sources away from windrows. If fires do start, break windrows apart and extinguish completely.
Center is dry and contains tough materials	Not enough water	Chip woody materials
		Moisten and turn
Inadequate composting rate	Material too dry	Add water initially, or as corrective measure during turning. Mix grass clippings into windrow.
	Windrows too large, leading to acidic and anaerobic conditions	Make windrows smaller, adding limestone if necessary to raise pH and control odors.
Piles are damp and sweet smelling, but will not heat up	Lack of nitrogen	Mix in a nitrogen source such as grass clippings or manure.
		(1:60; 29:38; 35:78)

Appendix F: Estimation Figures for Yard Waste

Density

Leaves

Loose	250 lbs/cubic yard
Vacuumed	350 lbs/cubic yard
Compacted	450 lbs/cubic yard

Grass

Assumption: 30 gallon bag used at 80% capacity = 24 gallons.
24 gallon bag of grass weighs approximately 50 lbs.

Then: 50 lbs/bag x 8.4 bags/cu yd = 420 lbs/cu yd.

Generation Rates

Leaves

Assumptions: Suburban environme ngle family units.

Variables: Size of lots, number of trees, degree of raking, compaction, moisture.
10-40 (avg. 15-20) bags/dwelling unit/year.
30 gal bag weighs from 20-30 lbs.

Then: 200-1200 lbs/dwelling unit (avg. from 375-500 lbs/dwelling unit/year).

Grass

Assumptions: 28 week growing season,
1 cut/2 weeks = 13 cuts/year.

Variables: Size of lots, rainfall, amount of fertilization, number of cuts.
1-2 bags/cut = 13-25 (avg. 20) bags/dwelling unit/year.
30 gallon bag = 40-60 (avg. 50) lbs.

Then: 20 bags x 50 lbs = 1000 lbs/dwelling unit/year.

Moisture

Leaves:	30-40%
Grass:	60-70%

Volume and Weight Reduction During Composting

Weight Loss:	30-50%
Volume Reduction	25-70%

(1:76)

Windrow Temperature Data Sheet

Data collected by:______________________ Date_________ Time of Day_______________

Weather information (sunny, rain, etc.)____

Wind direction (Northeast, South, etc.)____

Air temperature: °F ______ or °C_______ time of day_______________________________

Site observation comments (windrow turned, water ponding, odor, etc.) _______________

____

____

____

Windrow moisture (hand-fist squeeze observation) - circle response

Needs moisture Satisfactory Excess

Windrow temperature measurement location	Temperature Observation, °F or °C					
	Windrow Observation (See Sketch Below)					
	A	B	C	D	E	F
1						
2						
3						
4						
5						

Windrow # 1

A B C D E F

2

A B C D E F

3

A B C D E F

4

A B C D E F

5

A B C D E F

Observation Location

(35:77)

Sample Material Delivery Data Sheet

Month ______					Year ______				
	Vehicle No. ______ Type ______ Cap. Cu.Yd.		Vehicle No. ______ Type ______ Cap. Cu.Yd.		Vehicle No. ______ Type ______ Cap. Cu.Yd.		Vehicle No. ______ Type ______ Cap. Cu.Yd		
DATE	Loads	CY/Tons	Loads	CY/Tons	Loads	CY/Tons	Loads	CY/Tons	TOTAL
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									
11									
12									
13									
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18									
19									
20									
21									
22									
23									
24									
25									
26									
27									
28									
29									
30									
31									
total									

(29:73)

Appendix H: Worksheets for Estimating Benefits and Costs of Composting

Worksheet for Estimating Costs of Composting

1. Annual Operating Costs $/Year

A. Labor

1. Site monitoring and directing of trucks while leaves are being received:
   (________ hrs./wk) x (________ wks/yr) x ($ ________ /hr) = ________
2. Emptying of bags:
   (________ hr/cu yd) x (________ cu yd/yr) x ($ ________ /hr) = ________
3. Equipment operator during windrow formation
   (________ hrs./wk) x (________ wks/yr) x ($ ________ /hr) = ________
4. Truck driver if needed during windrow formation:
   (________ hrs./wk) x (________ wks/yr) x ($ ________ /hr) = ________
5. Compost process monitoring:
   (________ hr/visit) x (________ visits/wk) x
   (________ wks monitored/yr) x ($ ________ /hr) = ________
6. Equipment operator for turning of windrows
   (________ hr/turn) x (________ turns/yr) x ($ ________ /hr) = ________
7. Wetting of leaves:
   (______ hr/wetting) x (______ wettings/yr) x ($________ /hr) = ________
8. Other (shredding, loading, bagging, etc. as applicable) ($________) = ________
9. Site monitoring while compost is being sold or given away:
   (________ hrs./wk) x (________ wks/yr) x ($ ________ /hr) = ________

Total of hourly wages.. = ________

Costs of fringe benefits ($ ________) x (________ %).................... = ________

Total labor costs (total hourly wages plus costs of fringe benefits)............. = ________

B. Cash Expenses for Equipment (operating and maintenance costs and/or rental costs)

1. Front end loader during windrow formation:
   (________ hrs./wk) x (________ wks/yr) x ($ ________ /hr) = ________
2. Dump truck for moving leaves at the site:
   (________ hrs./wk) x (________ wks/yr) x ($ ________ /hr) = ________
3. Front end loader or other equipment for turning windrows:
   (_______ hr/turn) x (_______ turns/yr) x ($_______ /hr) = ________
4. Water truck (if needed):
   (_______ hr/wetting) x (_______ wettings/yr) x ($_______ /hr) = ________
5. Maintenance of roads, fences, drainage and water systems, and buildings = ________
6. Other equipment for shredding, loading, bagging, etc. as applicable = ________

Total cash expenses for equipment....................................... = ________

Worksheet for Estimating Costs of Composting (continued)

		$/Year
C. Supplies and Other Expenses		
1. Training of personnel	=	______
2. Replacement thermometers	=	______
3. Laboratory analyses of compost	=	______
4. Electricity	=	______
5. Water	=	______
6. Other	=	______
Total for supplies and other expenses	=	______
Total Annual Operating Costs (sum of parts A, B and C)	=	______
II. Annual Capital Costs (In each case start with the initial capital cost of the particular item and convert to an annual basis with a capital recovery factor (CRF) that includes an allowance for annual depreciation over the service life and annual interest on investment, see Appendix G. Since land does not depreciate, the CRF for land is the annual rate of interest.)		
A. Land ($______) x (______ CRF)	=	______
B. Site Improvements		
1. Site grading, drainage and roads ($______) x (______ CRF)	=	______
2. Fencing, gate, signs, and buffers: ($______) x (______ CRF)	=	______
3. Water system: ($______) x (______ CRF)	=	______
4. Gate house and storage shed: ($______) x (______ CRF)	=	______
5. Other	=	______
Annual capital costs for site improvements	=	______
C. Equipment (Let C/T stand for the ratio of composting usage to total usage)		
1. Front end loader: ($______) x (______ C/T) x (______ CRF)	=	______
2. Dump truck ($______) x (______ C/T) x (______ CRF)	=	______
3. Water truck: ($______) x (______ C/T) x (______ CRF)	=	______
4. Other equipment for turning windrows, shredding, bagging, etc.:		
($______) x (______ C/T) x (______ CRF)	=	______
($______) x (______ C/T) x (______ CRF)	=	______
Annual capital costs for equipment	=	______
Total Annual Capital Costs (sum of parts A, B and C)	=	______
Annual Costs of Composting (sum of parts I and II)	=	______

(17:27)

Worksheet for Summarizing Annual Economic Benefits and Costs from Composting

Item or Function		$/Year Municipal	$/Year Non-municipal
A. Benefits			
1. Avoided cost of incinerating or landfilling leaves	=	______	______
2. Value of compost used by the municipality	=	______	
3. Revenue from the sale of compost	=	______	
4. Value of compost used by residents and businesses in excess of payments to the municipality	=		______
5. Other revenues or benefits	=	______	______
Total Economic Benefit	=	______	______
B. Costs			
1. Change in collection costs (from Table 5)	=	______	______
2. Municipal costs of composting (from Table 6)	=	______	
3. Other costs	=	______	______
Total Economic Cost	=	______	______
Net Economic Benefit (Total Economic Benefit minus Total Economic Cost)	=	______	______

(17:29)

Appendix I: Compost Processing Equipment and Approximate Prices in 1990 (A Partial List)

Turners	Equip Type	Size/Capacity	Cost	Comment
Brown Bear	Model 200	115 hp 1,500 cu yd/hr 10'x 31" aerator head	$ 118,000	Auger moves compost to the side.
	Model 300	177 hp 3,000 cu yd/hr 10'x 3' aerator head	$ 140,000	"
	Model 400	225 hp 3,000 cu yd/hr 14'x 39" aerator head	$ 167,000	"
	Model 500	290 hp 4,000 cu yd/hr 12'x 4' aerator head	$ 195,000	"
Cobey Composting (Eagle Crusher Company)	Model 12A	225 hp 1000-2000 tons/hr 14'x 6'windrow	$ 135,000 to $ 185,000	Straddles windrow and drum lifts and turns compost
Resource Recovery Systems	K-W 614	300 hp 5,000 cu yd/hr 2000 ton/hr 14'x 6'windrow	$ 100,000	Straddles windrow and drum lifts and turns compost.
	hydraulically driven drum-optional		$ 50,000	
	K-W 616	300 or 440 hp 6000 cu yd/hr 2500 ton/hr 16'x 6'windrow	$125,000	
	K-W 718	440 hp 7500 cu yd/hr 3000 tons/hr 18'x 7'windrow	$160,000	

Turners	Equip Type	Size/Capacity	Cost	Comment
Scarab	Scarab 14	234 hp 2,000 tons/hr 14'x 6' windrow V-belt drive	$ 104,000	Straddles windrow and drum lifts and turns compost.
	Scarab 18	360 hp 3,000 tons/hr 18'x 7' (hydraulically driven)	$ 174,000	"
Scat	482B	65 hp 3,000 cu yd/hr 2,000 tons/hr 18'x 6' windrow	$ 55,000	2 pass type elevating face, needs 60 hp tractor to pull.
	483B	85 hp 4,000 cu yd/hr 3,000 tons/hr 20'x 9' windrow	$ 75,000	2-pass type elevating face, needs 80-100 hp tractor to tow.
	483I Larger or Custom units available	107 hp 4,000 cu yd/hr 3,000 tons/hr 20'x 9' windrow	$ 155,000	2-pass type self-propelled.
Wildcat	FX 700	300 tons/hr 14'x 4' windrow	$ 13,400	Needs 60-120 hp tractor with hydrostatic drive or creeper gear transmission.
	C700	400 tons/hr 14'x 4' windrow	$ 19,500	Needs 90-140 hp with hydrostatic drive.
	CX700M	117 hp 800 tons/hr 14'x 5' windrow	$ 22,000	Self-powered; mounted on 2 yd cap. front-end loader
	X750ME	177 hp 14'x 5' windrow 1,100 tons/hr	$ 70,000	Self-powered; mounted on 3 yd cap. front-end loader
	M700E Special	325 hp 2,600 tons/hr 18'x 7.5' tall	$ 100,000	Self-powered; mounted on 4 yd cap. front-end loader.

Grinders	Equip Type	Size/Capacity	Cost	Comment
Amadas Pulverizer	421	75 hp 40 cu yd/hr	$ 11,000	Hammermill
	430	100 hp 60 cu yd/hr	$ 14,000	Hammermill
	450	350 hp	$ 34,000	Hammermill
Farmhand	6650	100 cu yd/hr	$ 24,000	Large tub grinder w/ hammermill; single axis PTO driven tractors 100-200 hp.
Fuel Harvesters	Model P12-46HD	475 hp 10-25 ton/hr	$ 135,000	Large tub grinder hammermill
	Model 1000	25-30 tons/hr	$ 100,000 to $ 250,000	Chip screen plant
Haybuster	1000 Series Industrial Grinder	260 hp	$ 54,000	Tub grinder w/ hammermill
Jones Manufacturing	PTO	10 ton/hr	$ 36,000	Tub grinder w/ hammermill
	Power Unit	400-503 hp 15 ton/hr	$ 105,000	"
	Hydrofork - SN	400-503 hp 15 ton/hr	$ 150,000	"
Recycling Systems, Inc.	Industrial Tub Grinder	400-525 hp to 30 tons/hr	$ 130,000 to $ 175,000	Tub grinder w/ hammermill (loader optional)
Stumpmaster	57	530 hp 20-30 ton/hr	$ 149,000	Hammermill
	71	402 hp 20 ton/hr	$ 232,000	Hammer hog
	84	530 hp 30 ton/hr	$ 299,000	Hammer hog

Shredders	Equip type	Size/Capacity	Cost	Comment
Mitts & Merrill	MS-1714	10 hp	$ 17,500	Low speed, high torque hook/shear shredders
	MS-2817	20 hp	$ 35,000	
	MS-2833	30 hp	$ 55,000	
	MS-4220	50 hp	$ 70,000	
	MS-4526	75 hp	$ 110,000	
	MS-5028	125-150 hp	$ 180,000	
	MS-5040	200 hp	$ 320,000	
Morris-Knudsen	36 x 60	250 hp 15-50 ton/hr	$ 89,000	Heavy duty wood hog
	48 x 48	350 hp 20-75 ton/hr	$ 103,000	
	48 x 72	600 hp 30-100 ton/hr	$ 138,000	
Royer	182	25 cu yd/hr	$ 20,000	Two stage mixing of material.
	300	75 cu yd/hr	$ 48,000	Cleated-belt shredders
	365	125 cu yd/hr	$ 65,000	Separates nonshreddable
	401	250 cu yd/hr	$ 105,000	material from end product
Shred Tech	ST-10L	10 hp	$ 14,400	High torque, 0.5 ton/hr low energy shredders
	ST-20	15-20 hp 1.5 ton/hr	$ 28,300	Counter-rotating shafts with
	ST-36	30 hp	$ 43,500	hooked cutter
	ST-50	40-50 hp 3-4 ton/hr	$ 51,000	blades
	ST-100	80-100 hp 6-8 ton/hr	$ 110,000	
	ST-200	200 hp 25 ton/hr	$ 237,000	

(35:87-93)

Appendix J: Compost Processing Equipment Manufacturers (A Partial List)

The following is a list of manufacturers and vendors for various types of yard waste collection and processing equipment. It is intended to assist program planners and managers in locating available equipment for use in their yard waste composting program. An updated directory is published annually in BioCycle.

A. LEAF COLLECTION

1. Mechanical Scoops

Ag-Bag Corp.
P.O. Box 418
Astoria, OR 97103
503-325-2488

Athey Products Corp.
P.O. Box 669
Raleigh, NC 27602
919-556-5171

Tink Inc.
2361 Durham-Dayton Hwy.
Durham, CA 95938
915-895-0897

Walluski Western Ltd.
P.O. Box 642
Astoria, OR 97103
503-325-5187

2. Vacuum Equipment

American Road Machinery, Inc.
401 Bridge St.
Minera, OH 44657
216-868-7724

Athey Products Corp.
P.O. Box 669
Raleigh, NC 27602
919-556-5171

Ford-New Holland
500 Diller Ave.
New Holland, PA 17557
717-355-1930

Giant-Vac Mfg. Inc.
South Windham, CT 06266
203-423-7741

Gledhill Road Machinery Co.
P.O. Box 567
Gealion. OH 44833
419-468-4400

Haul-All Equipment Systems
4115-18 Ave. North
Lethbridge, Alberta,
Canada T1H 5G1
403-328-7719

Ultra Vac, Div. of Cannon Ind., Inc.
P.O. Box 23848
Milwaukee, WI 53228
414-354-6470

Vac-All Div., Leach Co.
P.O. Box 2608
Oshkosh, WI 54903
414-231-2770

B. CONTAINERS FOR YARD WASTE COLLECTION

1. Kraft Paper Bags

Bancroft Bag, Inc.
P.O. Box 35807
West Monroe, LA 71294
1-800-551-4950

Bemis Company, Inc.
P.O. Box 35807
Des Plaines, IL 60017
312-693-4300

Canover Industries, Inc.
4300 United Parkway
Schiller Park, IL 60176
708-671-6464

International Paper Co.
77 W. 45th St., Room 29-39
New York, NY 10036
212-536-7342

Mid America Packaging
P.O. Box 5870
Pine Bluff, AK 71611
1-800-225-7813

Midwest Paper Bag, Inc.
1057 Alden
Buffalo Grove, IL
60089-1304
708-459-7310

Set Point Paper Company, Inc.
31 Oxford Road
Mansfield, MA 02048
508-339-9300

Stone Container
1515 Woodfield, Suite 770
Schaumburg, IL 60173
312-240-6327

Union Camp Corp.
Bag Division/Retail Packaging
P.O. Box 8
Savannah, GA 31402
1-800-841-4520

S&O Corporation
P.O. Box 167
527 Layton Rd.
Gallaway, TN 38036
901-867-2223

2. Degradable Plastic Bags

Amko Plastics
12025 Tricon Road
Cincinnati, OH 45246
513-671-1777

Colonial Bags
205 E. Fullerton Ave.
Carol Stream, IL 60188
312-690-3999

Commercial Plastic Packaging
2322 E. 13th St.
Ames, IA 50010
515-233-2268

Composting Concepts
15843 S. 45th St.
Afton, MN 55001
612-436-5994

Home Plastics
5250 N.E. 17th Street
Des Moines, IA 50313
515-265-2562

Manchester Packaging
P.O. Box 67
St. James, MO 65559
314-265-3569

North American Plastics
921 Industrial Dr.
Aurora, IL 60506
312-896-6200

Petoskey Plastics, Inc.
U.S. 31
Petoskey, MI 49770
1-800-999-6556

Poly-Tech, Inc.
1401 West 94th St.
Bloomington, MN 55431
612-884-7281

Professional Supply, Inc.
4606 W. 138th St.
Crestwood, IL 60045
312-371-9140

Roll-Pak
1413 Eisenhower
Goshen, IN 46526
219-533-0541

Webster Industries
58 Pulaski St.
Peabody, MA 01960
508-532-2000

3. Bag Breaking Systems

The Heil Co., Engineered Systems Div.
P.O. Box 593
Milwaukee, WI 53201
414-647-3333

Lindemann Recycling
500 Fifth Ave. Suite 1234
New York, NY 10110
212-382-0630

Recomp, Inc.
1500 E. 79th St., Suite 102
Bloomington, MN 55420
612-854-6211

4. Wheeled Carts and Other Rigid Containers

Bonar Plastics
1 Valleywood Dr.
Markham, Ontario, Canada L3R 5L9
416-475-6980

Greif Brothers Corp.
P.O. Box 796
Hebron, OH 43025
614-928-0070

Kirk Manufacturing, Inc.
4052 Highway 56
Houma, LA 70363
504-868-9975

Neil Rotomold
P.O. Box 8676
Chattanooga, TN 37411
615-899-9100

Pawnee Products
P.O. Box 751
Goddard, KS 67052
316-794-2213

Reuter, Inc.
410 11th Ave. South
Hopkins, MN 55343
612-935-6921

Rubbermaid
3124 Valley Ave.
Winchester, VA 22601
703-667-8700

SSI Schaeffer
666 Dundee Rd., Suite 501
Northbrook, IL 60062
312-498-4004

Zarn Inc.
P.O. Box 1350
Reidsville, NC 27323-1350
919-349-3323

Master Cart
P.O. Box 12543
Fresno, CA 93778
209-233-3277

Otto Industrial, Inc.
12700 General Drive
P. O. Box 410251
Charlotte, NC 28241-0251
1-800-227-5885

Refuse Removal Sys, Inc.
7844 Madison Ave.
P.O. Box 2258
Fair Oaks, CA 95628
916-966-0496

Rotonic Molding Inc.
/Chicago
1320 Ardmore Ave.
Itasca, IL 60143
312-773-9510

Snyder Industries
P. O. Box 4583
Lincoln, NE 68504
402-467-5221

Toter Products, Inc.
P.O. Box 5338
Statesville, NC 28677
1-800-288-6837

C. WINDROW COMPOSTING EQUIPMENT

1. Front-end Loaders

C.C. Kelly & Son
61501 Brennen Highway
Mishawaka, IN 46544
219-255-4746

Elliott & Frantz, Inc.
450 East Church Rd.
King of Prussia, PA 19406
215-279-5200

Ford New Holland, Inc.
500 Diller Ave.
New Holland, PA 17557
717-354-1121

Tech-Line Instrument
P.O. Box 1236
Fond du Lac, WI 54935
1-800-328-7518

Du-al Manufacturing, Co.
1000 West Cherokee
Sioux Fall, SD 57117
605-336-3860

Foley Machinery Co.
Caterpillar
855 Centennial Ave.
Piscatawa, NJ 08854
201-885-3030

J.I. Case
700 State St.
Racine, WI 53404
414-636-6011

Long Mfg. N.C. Inc.
111 Fairview St.
Tarboro, NC 27886
1-800-334-5622

2. Windrow Turners

Brown Bear
P.O. Box 148
Lenox, IA 30851
515-333-4551

Kolmnan/Athey
P.O. Box 806
Souix Falls, SD 57101
605-336-2610

Scarab MFG & Leasing, Inc.
Route 2, Box 40
White Deer, TX 79097
806-883-7621

Cobey Composting
4250 S.R. 309
Galion, OH 44833
419-468-2288

Resource Recovery Systems
of Nebraska, Inc.
Rt. 4
Sterling, CO 80751
303-522-0663

SCAT Engineering &
Leasing, Inc
P.O. Box 266
Dehli, IA 52223
1-800-922-2981

Wildcat Mfg. Co., Inc.
Box 523
Freeman, SD 57029
605-925-4512

3. Screens

The Heil Co. Eng. Systems, Div
P.O. Box 593
Milwaukee, WI 53201
414-647-3333

Krebs Engineers
1205 Chrysler Drive
Menlo Park, CA 94025
415-325-0751

Lindig Manufacturing Corp.
Box-1877 W. County Rd.
St. Paul, MN 55113
612-633-3072

Powerscreen of America, Inc.
11300 Electron Dr.
Louisville, KY 40299
502-267-2316

Royer Industries, Inc.
P.O. Box 1232
Kingston, PA 18704
717-287-9624

Hobbs-Adams Engineering
1100 Holland Road
Suffolk, VA 23434
804-539-0231

Lindemann Recycling
500 Fifth Ave. Suit 1234
New York, NY 10110
212-382-0630

Parker Manufacturing, Inc
18012 Bothell Highway S.E.
Bothell, WA 98012
206-486-3547

Resource Recovery Systems
P.O. Box 33965
Detroit, MI 48232
519-736-5481

Sweco, Inc
P.O. Box 4151
Los Angeles, CA 90051

4 . Trommels

Falcon Equipment, Inc.
P. O. Box 339
Gardena, CA 90247
213-327-4880

Rader Companies, Inc.
P.O. Box 20128
Portland, OR 97220
503-255-5330

Lindemann of America, Inc
500 Fifth Ave. Suit 1234
New York, NY 10110
212-382-0630

Triple/s Dynamics, Inc.
1031 S. Haskell Ave.
Dallas, TX 75223
214-828-8600

D. SHREDDERS, GRINDERS, AND WOOD CHIPPERS

1. Shredders & Grinders

Presser Industries/Jeffery Mfg. Div.
P.O. Box 387
Woodruff, SC 29388
803-476-7523

Fuel Harvesters Equipment
12759 Loma Rica Dr.
Grass Valley, CA 95945
916-272-7664

Heil Engineered Systems
3000 W. Montana St.
Milwaukee, WI 53215
414-647-3350

Jacobson, Inc.
2445 Nevada Ave.
Minneapolis, MN 55427
612-544-8781

Lindemann Recycling Equipment
500 Fifth Ave., Suite 1234
New York, NY 10110
212-382-0630

Recycling Systems
P. O. Box 364
Winn, MI 48896
517-866-2800

Shredding Systems, Inc.
P.O. Box 869
Wilsonville, OR 97070
404-462-2445

Universal Engineering,
Div. of Pettibone Corp.
800 First Ave., NW
Cedar Rapids, IA 52405
319-365-0441

Farmhand, Inc.
6421 Hazeltine Blvd.
Excelsior, MN 55331

Hammermills, Inc.
800 First Ave., N.W.
Cedar Rapids, IA 52405
319-365-0441

Iggesund Recycling
P.O. Box 380
Nisswa, MN 56468
218-963-4343

Jones Manufacturing Co.
RR 1, Box 80
Beemer, NE 68712
402-528-3861

Olathe Manufacturing Inc.
100 Industrial Pkwy
Industrial Airport, KS 66031
1-800-255-6438

Saturn Shredders
201 E. Shady Grove Rd.
Grand Prairie, TX 75054

Stumpmaster, Inc.
P.O. Box 103
Rising Fawn, GA 30738

Valby Woodchippers
Northeast Implement Corp.
Box 402
Spencer, NY 14883
607-589-6160

2. Wood Chippers

Bandit Industries
6750 Millbrook Rd.
Remus, MI 49340
517-561-2270

Lindig Manufacturing
Box 106
St. Paul, MN 55113
612-633-3072

Olathe Manufacturing, Inc.
100 Industrial Parkway
Industrial Airport, KS 66031
913-782-4396

Valby Woodchippers
Northeast Implement Corp.
Box 402
Spencer, NY 14883
607-589-6160

E. MISCELLANEOUS

1. Marketing

American Soil Products
2222 Third St.
Berkeley, CA 94710
415-540-8011

Compost Management, Inc.
354 Main St., N.
Doylestown, PA 18901
215-348-9288

Kellogg Supply Co.
350 W. Sepulveda Blvd.
Carson, CA 90745
213-830-2206

Soil Products, Inc.
P.O. Box 145
Hermitage, TN 37076
615-889-4091

2. Temperature Probes

Atkins
3401 Southwest Fortiers Dr.
Gainesville, FL 32608
904-378-5555

Camx Scientific
P.O. Box 747
Rochester, NY 14603-0747
716-482-1300
Item No.5224x36;$82

Meriden Cooper Corp.
112 Golden St. Park
Box 692
Meriden, CT 06450
203-237-8448
Model:Tel-Tru GT 300R;$75

Omega Engineering, Inc.
One Omega Dr.
P.O. Box 4047
Stamford, CT 06907
1-800-826-6342
Cat. G-O-200oC-36-PB;$44
or, G-O-100oC-36-PB;$44

Reotemp Instrument Corp.
11568 Sorrento Valley Rd. #10
San Diego, CA 92121
619-418-7737
1-800-648-7737
Model:A;$56

Farmhand, Inc.
6421 HazeltineBlvd.
Excelsior, MN 55331
612-474-1941

Fuel Harvesters Equip.
12759 Loma Rica Dr.
Grass Valley, CA 95945
916-272-7664

Haybuster Mfg., Inc.
P.O. Box 1940
Jamestown, ND 58402
701-252-4601

Walden Inst. Supply Co.
910 Main St.
Wakefield, MA 01880
617-245-2944
Model:Ashcroft 30 EI50R 360;$57

3. Oxygen Analyzers

Markson Science, Inc.
P.O. Box 767
Del Mar, CA 92014
602-496-8447
1-800-528-5114
Sensitron Oxygen Analyzer
Cat#A-27040 with Sensor 27041;$263

4. Masks

3-M
3-M Center Bldg. 220-3E-04
St. Paul, MN 55144
1-800-328-1667

American Optical Corp.
P.O. Box 1979
Southbridge, MA 01550
1-800-225-7768

Glendale
Crossways Park Blvd.
Woodbury, NY 11797
516-921-5800

Lindig Mfg. Corp.
1875 West County Rd.,C
St. Paul, MN 55113
612-633-3072

Mac/Saturn Corp.
201 E. Shady Grove Rd.
Grand Prairie, TX 75050

Montgomery Industries
P.O. Box 3687
Jacksonville, FL 32206

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Appendix K: Glossary of Composting Terms

Acid. pH below 7 on scale of 0 to 14. Normal product of decomposition characterized by hydrogen ions.

Actinomycetes. Family of microorganisms belonging to a group intermediary between bacteria and molds (fungi); a form of filamentous, branching bacteria.

Aerated Static Pile. Composting system using controlled aeration from a series of perforated pipes running underneath each pile and connected to a pump that draws or blows air through the piles.

Aeration. Providing air and oxygen to aid aerobic decomposition.

Aerobic. Composting environment characterized by bacteria active in the presence of oxygen (aerobes); generates more heat and is a faster process than anaerobic composting.

Aerobic Composting. Decomposition of organic wastes by microorganisms in the presence of oxygen. See composting.

AFP. Air filled porosity; the air capacity of a compost.

Agricultural Waste. Waste materials produced from the raising of plants and animals, including manures, bedding, plant stalks, hulls, leaves and vegetable matter.

Air Classification. The separation of mixed waste materials using a moving stream of air; light wastes are carried upward while heavy components drop out of the stream.

Alkaline. pH above 7 on a scale of 0 to 14. Containing bases (hydroxide, carbonates) that neutralize acids to form salts.

Allelopathy. The suppression of growth of one plant species by another due to the release of toxic substances.

Anaerobic Digestion. Decomposition of organic wastes in the absence of oxygen.

Anaerobic. Composting environment characterized by bacteria active in the absence of oxygen (anaerobes).

Bacteria. Unicellular or multicellular microscopic organisms.

Batch Composting. All material is processed at the same time, without introducing new feedstock once composting has begun; windrow systems are batch systems.

Bench Scale Reactor. Laboratory system to model the composting process, usually using water baths to mimic large pile conditions.

Berm. A barrier adjacent to a facility to intercept and reflect water and noise; can also provide visual screening.

Bioassay. A laboratory assay (test) using a biological test organism.

Bioavailable. Available for biological uptake.

Biodegradability. The potential of an organic component for conversion into simpler structures by enzymatic activity.

Biogenic Waste. (Germany) The separated organic fraction of household waste; consists of yard and food waste.

Biological Oxygen Demand (BOD). The amount of oxygen used in the biochemical oxidation of organic matter; an indication of compost maturity and a tool for studying the composting process.

Buffer Zone. Area between the composting facility and homes or other sensitive land uses, that shields these neighboring uses from impacts of the operation. A buffer zone that is vegetated can contribute to visual screening and noise interception.

Bulk Density. Mass per unit volume of undisturbed soil, dried to constant weight at 105°C (221°F).

Bulking Agent. Material, usually carbonaceous such as sawdust or woodchips, added to a compost system to maintain airflow by preventing settlement and compaction of the waste.

Cadmium to Zinc Ratio (Cd:Zn Ratio). Ratio of the elements used to study heavy metal accumulation by animals.

Carbohydrates. Various kinds of sugars, generally easily assimilated by bacteria.

Carbon to Nitrogen Ratio (C:N Ratio). Ratio representing the quantity of carbon (C) in relation to the quantity of nitrogen (N) in a soil or organic material; determines the composting potential of a material and serves to indicate product quality.

Cation Exchange Capacity (CEC). A routine measure of the binding potential of a soil; measures the soil's ability to remove negative ions from metals and other compounds, allowing the ions to form insoluble compounds and precipitate in the soil; determined by the amount of organic matter and the proportion of clay to sand; the higher the CEC, the greater the soil's ability to bind metals.

Cellulose. Carbon component of plants, not easily digested by microorganisms.

Chemical Oxygen Demand (COD). A measure of the oxygen equivalent of that portion of organic matter in a sample that is susceptible to oxidation by a strong chemical oxidant; an important, rapidly measured parameter for stream and industrial waste studies and for control of waste treatment plants.

Co-Composting. Composting process utilizing carbon-rich organic material including leaves, yard waste, or mixed municipal solid waste, in combination with a nitrogen-rich amendment such as sewage sludge.

Compaction. Compressing wastes to reduce their volume. Compaction allows for more efficient transport, but may reduce aeration.

Compost Pad. An area within the composting site where organic materials are processed. If not a hard surface, the pad should be constructed of material that drains well and will support heavy equipment in all weather conditions.

Compost. The stabilized product of composting which is beneficial to plant growth; it has undergone an initial, rapid stage of decomposition and is in the process of humification.

Composting Facility. A facility that produces compost from the organic fraction of the waste stream.

Composting. The biodegradation, usually aerobic and thermophilic, that: involves a heterogeneous organic substrate in the solid state; evolves by passing through a thermophilic stage with a temporary release of phytotoxins; results in the production of carbon dioxide, water, minerals and stabilized organic matter.

Composting, Municipal. Solid waste management method whereby the organic component of the solid waste stream is biologically decomposed under controlled conditions; an aerobic process in which waste organic materials are ground or shredded and then decomposed to humus in windrow piles or in mechanical digesters, drums, or similar enclosures; results in volume and odor reduction, waste stabilization, destruction of pathogens, larvae and weed seeds; the final product is sufficiently stable for storage and land application without adverse environmental effects.

Condensate. Moisture in the air that is pulled through a compost pile.

Conductivity. A measure of the soluble salts in the soil; used as an overall indicator of the level of macro- and micronutrients in the soil.

Contaminant. Foreign material lending impurity to a primary material; physical contaminants of compost include glass and plastic, chemical contaminants include heavy metals and toxic organic compounds.

Continuous-Flow. A system of composting in which material is continuously added to the composting process and the end product is continuously removed; often used for large operations.

Controlled Dynamic System. Compost piles receive forced aeration and periodic turning. See Also: aerated static pile.

Cubic Yard. A standard measure of waste volume. There are 27 cubic feet in a cubic yard. For compacted leaves, one cubic yard is roughly equivalent to 500 pounds or 1/4 ton, assuming an average rate of compaction and moisture content.

Curing. Late stage of composting, after much of the readily metabolized material has been decomposed, which provides additional stabilization and allows further decomposition of cellulose and lignin.

Decomposition. Conversion of organic matter as a result of microbial and/or enzymatic interactions; initial stage in degradation of an organic substrate, characterized by processes of destabilization of the pre-existing structure.

Denitrification. The biological reduction of nitrogen to ammonia, molecular nitrogen or oxides of nitrogen, resulting in the loss of nitrogen into the atmosphere.

Dewatered Sewage Sludge. Sewage sludge with a total solids content of 6% or greater that can be transported and handled as a solid material; usually done by belt press, screw press, vacuum filtration or centrifuge.

Digester. An enclosed composting system with a device to mix and aerate the waste materials.

Digestion. The most active stage of the composting process; carried out in open windrows or in enclosures; the objective is to create an environment in which microorganisms will rapidly decompose the organic portion of the refuse.

Aerobic. Temperatures may reach over 140°F - high enough to destroy pathogens, weed seeds, and fly ova; creates no excessive unpleasant odors; the most rapid composting process occurs with enclosed aerobic systems.

Anaerobic. The microflora obtain oxygen from the waste; peak temperatures may reach 100 to 130°F; digestion requires more time, foul odors are created and pathogens may survive.

Drum Composting System. Enclosed cylindrical vessel which slowly rotates for a set period of time to break up and decompose material.

Dynamic Pile System. Compost piles receive forced aeration and are not turned. See Also: aerated static pile.

Enclosed System. See: In-Vessel.

Erosion. The removal of material from the surface of the land by weathering, running water, moving ice, wind and mass movement.

Facultative Aerobic Organisms. Organisms capable of growing under both aerobic and anaerobic conditions.

Fermentation. Anaerobic decomposition involving only organic compounds.

Finishing. Post-processing; screening, grinding, or a combination of similar processes to remove plastics, glass, and metals remaining after composting.

Flail. A metal flange or tine attached to a rotating shaft for moving, mixing, and aerating leaves.

Food Waste. Residual food from residences, institutions or commercial facilities; unused portions of fruit, animal or vegetable material resulting from food production.

Front-end Loader. A tractor vehicle with a bucket-type loader at the front end of the vehicle.

Fungi. Saprophytic or parasitic multinucleate organisms with branching filaments called hyphae, forming a mass called a mycelium; fungi bring about cellulolysis and humification of the substrate during stabilization.

Green Waste. Portion of the municipal waste stream consisting of grass clippings, tree trimmings and other vegetative matter.

Groundwater. Water in a zone of saturation below the ground surface.

Hammermill. Machine using rotating or flailing hammers to grind material as it falls through the machine or rests on a stationary metal surface.

Heavy Metals. Metallic elements with high molecular weights. Some elements present human health risks at certain concentrations; some may be phytotoxic to plants, and others may adversely affect livestock. While high concentrations can be harmful, low concentrations of some heavy metals such as copper and zinc are essential trace elements for life processes. Examples of heavy metals include: cadmium (Cd), copper (Cu), chromium (Cr), mercury (Hg), nickel (Ni), lead (Pb) and Zinc (Zn).

Humic Acid. The main constituent of humus, composed of proteins and lignins, dark brown to black in color.

Humification. The microbial synthesis of three-dimensional polymers of saccharides and phenols resembling gums and lignin; a process of storing

organic energy in compounds of high molecular weight which are slowly degradable (10-100+ years).

Humus. A complex aggregate of amorphous substances, formed during the microbial decomposition or alteration of plant and animal residues and products synthesized by soil organisms; principal constituents are derivatives of lignins, proteins and cellulose; humus has a high capacity for base exchange (CEC), combining with inorganic soil constituents, and for water absorption; finished compost may be designated by the general term humus.

Hydromulching. An application method using a water jet to spread a mulch emulsion on a land surface.

Immobilization. Conversion of an element from its inorganic form to its organic form within microbial or plant tissues, rendering it unavailable to other organisms or plants.

In-Vessel Composting. (also "Enclosed" or "Mechanical") System using mechanized equipment to rapidly decompose wastes in an enclosed area with controlled amounts of moisture and oxygen.

Incubation Study. Study done in a laboratory setting under controlled temperature and moisture conditions.

Inerts. Non-biodegradable products contained in wastes (glass plastics, etc.).

Inocula. Preconditioned microorganisms or compost product added to raw material to provide the appropriate microorganisms for decomposition.

Inorganic. Substance in which carbon-to-carbon bonds are absent; mineral matter.

Land Clearing Debris. Yard waste and prunings or stumps six inches or greater in diameter resulting from land clearing operations.

Land Reclamation. The restoration of productivity to lands made barren through processes such as erosion, mining or land clearing.

Leachate. Liquid which has percolated through solid wastes and extracted dissolved and suspended materials; liquid that drains from the compost mix.

Leaf Mold. Compost composed entirely of leaves, sometimes only partially decomposed.

Leaf Piles. A passive method of composting, where leaves are placed in large piles until a usable product is developed, a minimum of 2-3 years.

Lignin. The component of wood responsible for its rigidity.

Lipids. A generic term for all fats, oils and related fatty compounds.

Loading Rate. Measure of application amount, based on nutrients. trace metals or total mass of material.

Macronutrients. Nutritive elements needed in large quantities to ensure normal plant development (N, P, K, S, Mg, Ca, Fe).

Mature Compost. Compost that has been cured to a stabilized state, characterized as rich in readily available forms of plant nutrients, poor in phytotoxic acids and phenols, and low in readily available carbon compounds.

Mechanical. See : In-Vessel.

Mesophilic Stage. A stage in the composting process characterized by bacteria that are active in a moderate temperature range of 20 to 45°C (68 to 113°F); it occurs later, after the thermophilic stage and is associated with a moderate decomposition rate.

Mesophilic. Favoring an environment of moderate temperature between 40 to 110°F (4 to 43°C). Mesophilic microorganisms are most common at the beginning and later stages of the compost process.

Metabolism. Sum of the chemical reactions within a cell or whole organism, including the energy-releasing breakdown of molecules (catabolism), and the synthesis of complex molecules and new protoplasm (anabolism).

Microbe. See microorganism.

Microfauna. Small animals only visible with a microscope, including protozoa, nematodes, etc.

Microflora. Small plants only visible with a microscope, including algae, fungi, bacteria, etc.

Micronutrients. Nutritive elements needed in small quantities for healthy plant development; trace elements (Mn, B, Cl, Zn, Cu, Mo).

Microorganisms. Small living organisms only visible with a microscope.

Mineral-N. Nitrogen in its inorganic form, usually as nitrates or ammonium.

Mixed Waste Paper. Low-grade, potentially compostable paper, including noncorrugated paperboard, paperback books, telephone books, paper towels and paper containers.

Moisture Content. The mass of water lost per unit dry mass when the material is dried at 103°C (217°F) for eight hours or more. The minimum moisture content required for biological activity is 12-15%; it generally becomes a limiting factor below 45 or 50%; expressed as a percentage, moisture content is water weight/wet weight.

Mulch. Any suitable protective layer of organic or inorganic material applied or left on or near the soil surface as a temporary aid in stabilizing the surface and improving soil microclimatic conditions for establishing vegetation; mulch reduces erosion and water loss from the soil and can be used to control weeds.

Mulching. The application of a layer of compost to the surface of the soil, creating an interface that accepts water readily yet resists moisture loss through evapotranspiration.

Municipal Solid Waste (MSW). Residential and commercial solid waste generated within a community.

Mushroom Compost. Cellulose-rich organic matter, such as manure and straw, that has undergone the initial decomposition stage of a controlled composting process; used by mushroom growers.

Mycorrhiza. Soil-borne fungi that invade the roots of vascular plants and establish a symbiotic relationship; mycorrhiza hyphae, filaments that extend from plant roots, increase the surface area for nutrient and water absorption.

N:P:K Ratio. The ratio of nitrogen to phosphorus to potassium in a compost product; indicates fertilizer value.

Nematodes. Elongated, cylindrical, unsegmented worms; includes a number of plant parasites (a cause of root damage) and human parasites.

Nitrification. The oxidation of ammonia to nitrite and nitrite to nitrate by microorganisms.

Non-compostable. Incapable of decomposing naturally or of yielding safe, non-toxic end products. Non-compostable materials include glass, batteries, cans, etc.

Nutrients. Minerals and organic compounds that provide substance for organisms.

Obligate Aerobic Organisms. Can only grow in the presence of oxygen.

Organic. Substance which includes carbon-to-carbon bonds.

Organic Waste. Waste composed of materials that contain carbon-to-carbon bonds and are biodegradable. Includes paper, wood, food wastes, yard wastes and leaves.

Organic Matter. Portion of the soil that includes microflora and microfauna (living and dead) and residual decomposition products of plant and animal tissue; any carbon assembly (exclusive of carbonates), large or small, dead or alive, inside soil space; consists primarily of humus.

Organic Contaminants. Synthetic trace organics include pesticides and polychlorinated biphenyls (PCB's).

Organic-N. Nitrogen in organic material.

Oxidation. Energy-releasing process involving removal of electrons from a substance; in biological systems, generally by the removal of hydrogen (or sometimes by the addition of oxygen); chemical and/or biochemical process combining carbon and oxygen and forming carbon dioxide (CO_2).

Oxygen Demand. See: BOD and COD.

Pathogen. An organism, chiefly a microorganism, including viruses, bacteria, fungi, and all forms of animal parasites and protozoa, capable of producing an infection or disease in a susceptible host.

PCB's. Polychlorinated Biphenyls; a class of chlorinated aromatic hydrocarbons representing a mixture of specific, biphenyl hydrocarbons which are thermally and chemically very stable; some are proven carcinogens

Percolation. Downward movement of water through the pores or spaces in rock or soil.

Persistence. Refers to a slowly decomposing substance which remains active in the natural cycle for a long period of time.

pH. The negative logarithm of the hydrogen ion concentration of a solution, a value indicating the degree of acidity or alkalinity; pH 7 = neutral, pH < 7 = acid, pH > 7 = alkaline (basic).

Phytotoxic. Detrimental to plant growth; caused by the presence of a contaminant or by a nutrient deficiency.

Phytotoxin. Substance causing growth reduction or death in plants.

Preparation. Treatment of materials prior to composting, including grinding, shredding, sorting and adding sewage sludge.

Protein. Constituent of living matter containing nitrogenous compounds.

Putrescible Waste. Organic materials prone to degrade rapidly, giving rise to obnoxious odors.

Resource Recovery. A term used to describe the extraction of economically useful materials and/or energy from solid waste. Often refers to the burning of waste for energy.

Respiration. The metabolic function of consuming oxygen.

Runoff. Any liquid originating from any part of a composting facility that drains over the land surface.

Screening. The sifting of compost through a screen to remove large particles and improve the consistency and quality of the end product.

Self-heating. Spontaneous increase in temperature of organic masses resulting from microbial action.

Semi-mature Compost. Material in the mesophilic stage (it has passed though a thermophilic stage); the material will reheat to 20°C above ambient temperature; organic matter has been reduced by 40-60%.

Septage. Liquid and solid material pumped from a septic tank or cesspool during cleaning.

Shredder. Mechanical device used to break waste materials into small pieces.

Size Reduction. Generic term for breaking up solid waste or other materials into small pieces through crushing, chipping, shredding, grinding, etc.; the process makes wastes easier to separate and in increases surface area for composting.

Sludge. Solid residue of the wastewater purification process, a product of screening, sedimentation, filtering, pressing, bacterial digestion, chemical precipitation and oxidation; primary sludge is produced by a sedimentation process and secondary sludge is the product of microbial digestion.

Slurry. A thin watery mixture of a fine insoluble material.

Soil Amendment/Soil Conditioner. Soil additive which stabilizes the soil, improves resistance to erosion, increases permeability to air and water, improves texture and resistance of the surface to crusting, eases cultivation or otherwise improves soil quality.

Soil Profile. The characteristics of the soil and how they change with depth. Coloration and other features can be used to determine soil types, texture, and seasonally high water table.

Solid Waste. Garbage, refuse and other discarded solid materials, including such materials resulting from industrial, commercial, and agricultural operation and community activities.

Stability. State or condition in which the composted material can be stored without giving rise to nuisances or can be applied to the soil without causing problems there; the desired degree of stability for finished compost is one in which the readily decomposed compounds are broken

down and only the decomposition of the more resistant biologically decomposable compounds remains to be accomplished.

Stabilization. Stage in composing following active decomposition; characterized by slow metabolic processes, lower heat production and the formation of humus.

Staging Area. A temporary holding area where newly received leaves are received, mixed or debagged before being transfered to a compost pad.

Static Pile Composting. A method of composting in which oxygen and temperature levels are mechanically controlled by blowing air through a large stationary pile.

Static Pile System. An aerated static pile with or without a controlled air source; See also: controlled dynamic; dynamic.

Swale. A slight depression often for drainage, in the midst of generally level land.

Synergism. The simultaneous action of separate agencies which, together, create a greater total effect than the sum of their individual effect.

Thermophilic Stage. A stage in the composting process characterized by active bacteria which favor a high temperature range of 45 to 75°C (113 to 167°F); it occurs early, before the mesophilic stage, and is associated with a high rate of decomposition.

Thermophilic. Favoring higher temperatures ranging from 113 to 155°F (45 to 68°C). Thermophilic microorganisms thrive when the compost pile heats up.

Tilth. The physical state of the soil that determines its suitability for plant growth taking into account texture, structure, consistency and pore space; a subjective estimation, judged by experience.

Topsoil. Soil consisting of various mixtures of sand, silt, clay and organic matter; considered to be the nutrient-rich top layer of soil that supports plant growth.

Toxicity. Adverse biological effect due to toxins and other compounds.

Toxin. Unstable poison-like compound of biological origin which may cause a reduction of viability or functionality in living organisms.

Trough. Semi-enclosed windrow with automatic turning equipment mounted on retaining walls.

Vector. An animal or insect that transmits a disease-producing organism, including rats, mice, mosquitos, etc.

Vermicomposting. The biological degradation of organic matter contained in agricultural, urban and industrial wastes, occurring when earthworms feed on these materials.

Vermiculture. Composting by the activity of earthworms; material is eaten by the worms, leaving air passages which maintain aerobic conditions: the process is completed with a curing stage.

Volatilization. Gaseous loss of a substance to the atmosphere.

Volume Reduction. The processing of waste materials to decrease the amount of space they occupy. Compaction, shredding, composting and burning are all methods of volume reduction.

Wet Ton. Two thousand pounds of material, "as is". It is the sum of the dry weight of the material plus its moisture content. Yard waste weighed on truck scales would typically be reported this way.

Windrow Composting. A method of composting leaves in elongated piles. The piles or "wind rows" are turned periodically to aerate and mix the leaves, speeding up the decomposition process and reducing odors.

Windrow System. Waste/bulking agent mixture is placed in elongated piles, windrows,and aerated by mechanically turning the piles with a machine such as a front-end loader or specially designed equipment.

Wood Waste. Finished lumber, wood products and prunings or stumps six inches or greater in diameter.

Yard Waste. Grass clippings, leaves and weeds, and prunings from residences or businesses six inches or less in diameter.

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13. ABSTRACT (*Maximum 200 words*)
This thesis reviews composting as a solid waste management option for the Air Force. The Air Force's Pollution Prevention Program mandates composting as an opportunity to reduce landfill disposal and save future environmental costs. This research considers composting technologies used in mixed municipal solid waste and yard waste applications. The thesis presents the technical aspects of composting and also summarizes operational techniques of successful composting sites across the United States.

Composting is a biological process for converting organic wastes into a stable product for use as a soil amendment or mulch. The Air Force should immediately begin yard waste composting programs to avoid landfill costs and to produce a natural, usable end product. This thesis is not meant to be inclusive of all information required to begin a composting program, but provides insight into the decision making process and the criteria that are important to the success of composting yard waste. Included is an outline for starting a composting program and a step by step discussion to implement low-level technology composting. Recommendations provided by this research are applicable to all Air Force bases and offer a high probability of success for attaining the Air Force's solid waste reduction goals.

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